R 28/2/987

PROCEEDINGS

U.S. Army Corps of Engineers
Sixth Remote Sensing
Symposium

PRACTICAL APPLICATIONS OF
REMOTE SENSING DATA TO
PROJECT MANAGEMENT

November 2-4, 1987
Galveston, Texas, USA

D 103. 2:

READEX FICHE best copy available

PROGRAM DIRECTOR

David E. Lichy

U.S. Army Corps of Engineers
Water Resources Support Center
Ft. Belvoir, VA

PROGRAM COORDINATOR

David Petit

U.S. Army Engineer District
Galveston, TX

PROGRAM COMMITTEE

Barry Rought
Gary Earls

U.S. Army Engineer Division Southwestern
Dallas, TX

Edited by:

Arlene J. Nurthen

U.S. Army Corps of Engineers
Water Resources Support Center
Institute for Water Resources
Ft. Belvoir, VA

Sponsored By:

US Army Corps of Engineers

Water Resources Support Center
Fort Belvoir, Virginia

Hosted By:

Southwestern Division
Dallas, Texas

1937-1987
50th ANNIVERSARY

Galveston District
Galveston, Texas

A CENTURY OF SERVICE
ESTABLISHED 1880

TABLE OF CONTENTS

Page

OPENING SESSION

Symposium Overview
Barry Rought, Chief of Planning Division,
Southwester Division 1

Keynote Address
E. R. Heiberg, III, LTG
Chief of Engineers, USACE 3

Space Station-Polar Platforms Operational Instrumentation
Bruce H. Needham, Polar Platform Payload Manager
Washington, DC 9

SESSION I

Construction, Operations and Maintenance

Chairman: **George Rochen**, Chief of Operations Division
Galveston District

1. GOES DATA COLLECTION SYSTEM
John Nichols 11

2. MEASUREMENTS AND PREDICTION OF BANK EROSION AT ARCHAEOLOGICAL SITES ON CORPS OF ENGINEERS RESERVOIRS USING SEQUENTIAL AERIAL PHOTOGRAPHS
James Ebert, Eileen Camilli, LuAnn Wandsnider and James J. Hester 12

3. MONITORING AQUATIC MACROPHYTES USING TM DIGITAL DATA
David Johnson... 36

4. THE ENVIRONMENTAL PROTECTION AGENCY'S REMOTE SENSING SUPPORT OF THE CLEAN WATER ACT'S SECTION 404 ENFORCEMENT ACTIVITY
Peter M. Stokely.. 37

5. USE OF SPOT HRV DATA IN CORPS OF ENGINEERS DREDGING OPERATION IN LAKE ERIE
Carolyn J. Merry, Ike McKim, N. LaPotin and J. Adams 49

6. LOCATING SUSPENDED SEDIMENT SOURCES AND SINKS WITH LARGE LANDSAT DATA SETS
Mike Fedosh 59

7. INTERPRETATION OF AERIAL IMAGERY TO DETERMINE PLACES, TIMES AND EXTENT OF ILLEGAL WETLAND FILLS
Bill Clements and Frank Flynn 61

8. THE USE OF SPATIAL DATA BASES AND DATA BASE MANAGEMENT SYSTEMS TO IMPROVE PLANNING FOR AND CONTROL OF THE DISPOSAL OF DREDGED MATERIAL
Cynthia A. Abrahamson, Andrew J. Bruzewicz and Mark Johnson 64

SESSION II

Water Supply and Flood Control

Chairman: **Barry Rought**, Chief of Planning Division, Southwestern

9. APPLICATION OF POLAR-ORBITING NOAA/AVHRR AND TOVS DATA FOR WATER RESOURCES MANAGEMENT OF THE GREAT LAKES
Roger L. Gauthier and Karen H. Lee 67

10. DETERMINING AREAL FLOOD EXTENT IN SAGINAW COUNTY, MICHIGAN WITH LANDSAT THEMATIC MAPPER DATA
Karen H. Lee, Wendy S. Hutchinson and Roger L. Gauthier 68

11. EMERGENCY OPERATION FLOOD AND FLOOD STORAGE FORECAST MAPPING: A SOLUTION BY SATELLITE AND SIMULATION
Jack Stoll 70

12. THE ACQUISITION AND USE OF USGS DIGITAL ELEVATION MODELS
Henry A. Edwardo, Judith A. Tutino and Carlton E. Hackett 71

13. REMOTE SENSING OF SUSPENDED SEDIMENTS OF LAKE CHICOT, ARKANSAS
Frank Schiebe, J. A. Harrington, Jr., and J. C. Ritchie 77

14. UTILIZATION OF LANDSAT TM FOR FLOODPLAIN ASSESSMENT IN THE TRINITY RIVER TEXAS EIS
Tamie Morgan and Jack Stoll 86

SESSION III

Navigation and Coastal Engineering

Chairman: **Bill Wooly**, Chief of Planning, Galveston District

15. DEVELOPMENT OF USE OF A WETLAND DATA BASE TO EVALUATE NAVIGATION IMPACTS IN THE ST. MARY'S RIVER, MICHIGAN
Donald C. Williams 87

16. INTERPRETATION OF COASTLINE CHANGE IN BERRIEN COUNTY, LAKE MICHIGAN USING DIGITIZED AERIAL PHOTOGRAPHY
Karen Hartsell Lee and Charles L. Thompson 88

17. THE USE OF DIGITAL HABITAT MAPS IN STUDYING LANDSCAPE PROCESSES: EFFECT OF SPATIAL FACTORS ON LAND LOSS
Scott G. Leibowitz and John M. Hill 92

18. INFLUENCE OF LAND COVER ON BARRIER ISLAND EROSION AS DETERMINED FROM PHOTOGRAPHIC AND DIGITAL IMAGERY
L. Dorsey Worthy, Jr., John M. Hill and Irving A. Mendelssohn 102

19. PHOTOGRAMMETRIC MEASUREMENTS OF 42-TON DOLOS MOTIONS ON THE OUTER BREAKWATER AT CRESCENT CITY, CALIFORNIA
Thomas R. Kendall, Richard B. Davis and Jeff Leach 103

SESSION IV

Environmental Assessment and Modeling

Chairman: **Major John E. Rigby**, Deputy District Engineer
Fort Worth District

20. AN ELEVATION STRATIFIED LAND COVER EVALUATION IN THE DEVILS LAKE BASIN, NORTH DAKOTA
R. Melloh, R. Anfang, and N. LaPotin 119

21. THE RED RIVER ARCHEOLOGICAL PROJECT: THE APPLICATION OF REMOTE SENSING
W. J. Bennett, Jr., Lawson M. Smith and Mark Laustrup........ 135

22. WETLAND DELINEATION USING MULTI-TEMPORAL LANDSAT THEMATIC MAPPER DATA
Ross S. Lunetta, James G. Frickle and Wendy S. Hutchinson........ 136

23. EVALUATIONS OF THE ST. MARY'S RIVER ENVIRONMENT USING AIRBORNE MULTISPECTRAL SCANNER DATA
John. G. Lyon, Ross S. Lunetta and Donald C. Williams........ 137

24. USE OF LANDSAT MSS DATA TO ESTIMATE DROUGHT CONDITIONS PRECEDENT FLOW CONDITIONING, AND TREE GROWTH OF BOTTOMLAND HARDWOODS OF THE NECHES RIVER BASIN, TX
Paul M. Hathorn and Samuel F. Atkinson........ 138

25. GOES SATELLITE DATA AND GIS TECHNOLOGY HAVE A FUTURE IN HABITAT ANALYSIS
Jack Stoll, Steve Bong, and Ross S. Lunetta........ 161

26. INTEGRATION OF LOW ALTITUDE MSS DATA WITH HABITAT EVALUATION PROCEDURES
Joe Paxton and Bill Hazard........ 162

27. ESTABLISHING FLOW/AREA RELATIONSHIPS OF RIVERAIN GRAVEL WITH REMOTELY SENSED IMAGERY
Bill Clement and Jeff Hepler........ 180

28. DETERMINATION OF CRITICAL EROSION AREAS WITHIN AN URBAN WATERSHED USING LANDSAT TM AND THE UNIVERSAL SOIL LOSS EQUATION
Ken M. Morgan, Rick Sinclair, and David Koger........ 184

SESSION V

Geographic Information Systems Related to Water Resources Activities

Chairman: **Bill Klesh**, Headquarters, USACE

29. DEVELOPING A NATURAL RESOURCE INVENTORY AND MANAGEMENT METHODOLOGY-A CASE STUDY
Michael R. Waring and Bruce E. Davis........ 193

30. THE LAND MANAGERS DILEMMA: MONITORING MULTIDIMENSIONAL RESOURCES ASSOCIATIONS IN A THREE DIMENSIONAL WORLD
James Farley 198

31. NEW CAPABILITIES FOR HYDROLOGIC ENGINEERING AND PLANNING
W. G. Brooner, M. C. Place, and A. D. Feldman 222

32. A PILOT STUDY TO EVALUATE BACKWATER HABITAT ON THE GREEN RIVER USING AERIAL PHOTOGRAPHY AND GIS
M. J. Pucherelli, R. C. Clark, S. Wilds,
J. N. Hall, and R. Williams 227

33. THE IDENTIFICATION OF ARCHEOLOGICAL SITE PATTERING THROUGH INTEGRATION OF REMOTE SENSING, GEOGRAPHIC INFORMATION SYSTEMS, AND EXPLORATORY DATA ANALYSIS
W. Fredrick Limp 232

34. REMOTE SENSING AND GIS, PREDICTING SEDIMENT LOADING AND NUTRIENT EXPORT FOR WATERSHED MANAGEMENT
Samuel F. Atkinson 263

35. INTEGRATING GIS AND REMOTE SENSING DATA
D. G. Goodenough, K. B. Fung,
and W. J. Craig 264

36. DEVELOPMENT OF A GEOGRAPHIC INFORMATION SYSTEM FOR THE SAYLORVILLE RIVER BASIN, IOWA
Carolyn J. Merry, N. LaPotin, Thomas Eagle,
and J. Gardner 265

SESSION VI

USACE Remote Sensing Technology Transfer of Research and Development Results

Chairman: **Ed Link**, Technical Director, CRREL, Hanover, NH

CRREL'S EXPERIENCES OF REMOTE SENSING TECHNOLOGY TRANSFER TO THE CORPS USER
Carolyn J. Merry 271

REMOTE SENSING TECHNOLOGY TRANSFER: A COMPLEX EXPERIENCE
Jack Stoll 274

DEMONSTRATING THE USE OF SHORE-BASED RADARS FOR SENSING COASTAL OCEAN PARAMETERS
David Driver 275

TECHNOLOGY TRANSFER OF THE CORPS HYDROLOGIC MODELS
Arlen Feldman 276

TECHNOLOGY TRANSFER: A PRESCRIPTION FOR SUCCESS
Andy Bruzewicz 283

A PROPOSED REMOTE SENSING ASSISTANCE CENTER FOR THE CORPS OF ENGINEERS
Harlan L. McKim 284

ADDITIONAL POSTER SESSION PAPERS AND ABSTRACTS

WETLANDS MAPPING-SHREVEPORT, LOUISIANA, AIDED WITH INFRARED PHOTOGRAPHY
Manual Barnes 285

QUICK RESPONSE MONITORING OF HURRICANE JUAN FLOODING IMPACTS IN LOUISIANA, UTILIZING NOAA/AVHRR SATELLITE IMAGERY
Robert H. Cunningham, Cecil W. Soileau, Donald R. Wiesnet, and Morris Deutsch 286

ADVANCED IDENTIFICATION OF DISPOSAL AREAS
G. E. Justis 287

THE USE OF SPOT AND TM IMAGES IN DETERMINING WATER QUALITY AT SAYLORVILLE LAKE RESERVOIR, IOWA
Cynthia A. Abrahamson, Clinton A. Beckert, Andrew J. Bruzewicz, Nancy LaPotin, and Carolyn J. Merry 292

POCONO WETLANDS STUDY SUMMARY
Peter M. Stokely 294

APPLYING SPACE-AGE TECHNOLOGIES TO WATER DEVELOPMENT IN ARID AREAS
Farouk El-Baz 296

DETERMINATION OF CRITICAL EROSION AREAS WITHIN AND URBAN WATERSHED USING LANDSAT TM AND THE UNIVERSAL SOIL LOSS EQUATION
Ken M. Morgan, Rick Sinclair, and David Koger 298

CONCEPT FOR A DIGITAL FLOOD HAZARD DATA BASE
Daniel M. Cotter and Richard K. Campbell 299

COMPUTING, DIGITIZING AND MAPPING AREAS FROM AIRCRAFT PHOTOGRAPHY ON A MICROCOMPUTER SYSTEM
Pat O'Neil 300

REMOTE SENSING FOR WATERSHED MANAGEMENT
Denice Shaw 301

THE ROLE OF REMOTE SENSING AND GIS IN DETERMINING BANK PROTECTION PROGRAM EFFECTIVENESS
Phillip E. Orlowski 302

INTEGRATED SATELLITE IMAGERY AND CADD FOR WATERSHED MANAGEMENT, 404 PERMITTING AND ENVIRONMENTAL IMPACT ASSESSMENT
Aubie J. Oslin 303

MITAS: A NEW SYSTEM FOR INTERACTIVE MULTISPECTRAL SCENE ANALYSIS
R. Karalus, C Sheffield, M. Place and A. Downs 318

CAPABILITIES AND LIMITATIONS OF CD-ROM OPTICAL DIGITAL DISKS FOR STORING REMOTE SENSING DATA; TRENDS IN REMOTE SENSING AND GIS'S
Daniel J. Costanzo 320

DESIGN ISSUES: INTEGRATING IMAGERY AND OTHER GEOGRAPHIC DATA SOURCES WITHIN GRASS
Michael Shapiro, William Gorna, and Robert Lozar 321

REMOTE SENSING AND COMPUTER MAPPING ACTIVITIES OF THE TEXAS NATURAL RESOURCES INFORMATION SYSTEM
Charles Palmer 323

APPLICATIONS OF LANDSAT TM FOR THE DEVELOPMENT OF THE COOPER LAKE MASTER PLAN
Tamie R. Morgan 324

THE CORPS DEVELOPMENT OF A HELICOPTER LIDAR BATHYMETER SYSTEM
W. Jeff Lillycrop and Joan Pope 325

APPENDIX A:

LIST OF ATTENDEES 329

LIST OF COMMERCIAL EXHIBITORS 337

OPENING SESSION

SIXTH REMOTE SENSING SYMPOSIUM
OVERVIEW

BARRY G. ROUGHT, P.E.
CHIEF OF PLANNING, SOUTHWESTERN DIVISION

Welcome to the Southwestern Division and the Galveston District. This symposium has the makings of one of the most interesting of all. I say this not only because of the theme: "Practical Applications of Remote Sensing to Project Management"; the agenda of presenters and their subsequent poster sessions; the fine exhibitors and their displays; but most of all because of YOU, the attendees.

Assembled here are representatives of government agencies (Federal, state, and local), private companies, and interested individuals. The common ground of all that is here is a desire to apply technology to obtain a professional high quality job at the least cost and in the shortest time. You are the innovators who can recognize the opportunities and take advantage of the offering and apply it to your situation. The tutorials this morning were thought provoking and should set the stage for subsequent presentations.

It is fitting to hold the Sixth Symposium so close to Houston, where the 1st Corps Remote Sensing Symposium convened in 1975. Some of you here today may recall the exciting promises described at that time. Those promises were slow to become reality. But today, as you will see from the presentations and displays, the technology is finally at hand. This symposium has an equally exciting promise. A promise of the applications of a proven technology to a better product for our customers.

It is frustrating bringing new technology to an organization. Generally, supervisors who grew up under an "Older" system, have trouble understanding the "New", and have been slow in adopting these new methods. We have all heard supervisors, engineers, and non-believers, say:

We will try it once but...
We need results--not research!
If the labs develop it--prove it--I'll use it (Maybe)?

In this morning's tutorials, Dr. Maggio hit the key in that the decision makers must be able to understand the results and enough about the process to feel comfortable with the decision.

During the next 3 days you will hear presentations on application of remote sensing that work! You will see displayed equipment, software, and services that have worked are working. You will have the opportunity to probe and question presenters and exhibitors during the poster sessions and exhibits. You will hear key officials, including my Chief, General Heiberg, tell why this technology is important and what they expect. Most of all you will be able to exchange ideas, thoughts, and comments, in a pleasant surrounding with other interested participants.

In closing, let's reflect on our Constitution. It is a document written by innovative men to get the job done. Those men were using the past old technologies of government to craft a new philosophy for a future technology of government. Remote Sensing needs people like the framers of the Constitution. Not old and young people who "Think Old", but young and old people who "Think Young." Let's let the Right side of our brains function through the next 3 days.

KEYNOTE ADDRESS

LTG E. R. HEIBERG III
COMMANDER, USACE

I. INTRODUCTION

Glad to be with you. Been a few years since I've had this pleasure, and a lot has transpired in the meantime. Back when I was in ORD, remote sensing was a new technology. Now it's part of the way we do business in most of our districts.

But the Corps has also changed just since your last symposium 2 years ago, and changed in ways that have some significance for our use of remote sensing technology. I will discuss those changes shortly.

It's good to see such a fine attendance. And I understand some 40 of you are presenting papers on your use of this technology. I'm pleased to see this level of activity, because it shows you are interested in working smarter.

And one of the things we in the Corps must do more of is work smarter.

Let me talk a moment about some of the changes in the Corps, and the challenges we face.

II. WATER RESOURCES DEVELOPMENT ACT OF 1986 (WRDA '86)

The Water Resources Development Act of 1986 is having a significant impact on the way we do our business, for two important reasons.

One, for the first time in some 16 years, it gives us a lot of new work to do, and establishes a mechanism for authorizing continued new work. That means we've got quite a job to do.

And two, the Act calls for increased cost-sharing by project sponsors.

By putting a substantial amount of their money at stake, the local sponsors have an avid interest in what we do, how fast we do it, and what it costs. They have limited budgets, competing priorities, and constrained mechanisms for raising revenue. They must think hard about initial costs, cost escalation, and completion schedules. They want affordable projects, wise investment of their money, responsive accounting, and maximum return for their project dollar. And they don't want to wait 20 years for a project to be built. They are very interested in what we're doing and how we're doing it.

We must have good data with which to make our decisions--timely, accurate data. And we must have good data to justify our costs to the local sponsors. And we need to know the consequences of all of our decisions.

The Corps of Engineers now has a partner in this process, the local sponsor, who, by virtue of his 50 percent financial participation, must necessarily have a voice in the process. The first reconnaissance phase, which is still done at 100 percent Federal cost, must now be completed within 12 months, but it must be of sufficient detail to give a reasonable indication that further study will be worthwhile. Neither the Federal government nor local interests want to go into this further study unless they have a pretty good feeling that they will ultimately come out with a favorable project or recommendation.

The key environmental problems and concerns must be identified very early in the process. We heard some concern that the environment will be adversely affected because local partners will not be willing to accept or consider environmental problems or concerns. However, WRDA '86 did not eliminate any statutes or requirements relating to the environment. There is no change in what needs to be done, but the justification may have to be more clearly articulated and demonstrated.

All this points to the need for better information--faster, more accurate information.

III. INFORMATION MANAGEMENT

You may have noticed that information management is getting increased attention within the Army and within the Corps.

In his 1982 best seller, "Megatrends," John Naisbitt listed the most important megatrend as America's new information economy. . . Where we used to be primarily an agricultural society, and later predominantly an industrial society, we are today "a nation of information workers."

He notes that most of us work with information, rather than producing goods.

And that is true of USACE! Our contractors move earth, but in the course of our planning and decision making and managing, we are actually collecting, analyzing, managing, and distributing information! That's why we created the information management stovepipe.

The problem has been that we weren't getting reliable information where and when we needed it. Engineers couldn't get the finance and accounting information they needed, our hardware didn't do what's required, each "stovepipe" has its own system, and the systems don't talk to each other! We've realized we cannot operate that way.

The Corps of Engineers Corporate Information System Plan is our way to fix this. It consists of two parts. One is the Information Systems Modernization Program, called the ISMP, which will develop new data bases and applications to handle all our information needs. The other is the Corps of Engineers Automation Plan, or CEAP, which is the plan for acquiring the hardware and software needed to support the modernized program.

This is a sweeping program. We are looking at CORPS requirements--as opposed to stovepipe requirements--to see what information we need, and also what we've got. We want to develop new data bases that will enable us to input a given piece of data only once, and have it accessible to whoever needs it. I might add that one of the guiding principles is that the system be developed to satisfy operation requirements at the District level, as opposed to reporting to higher headquarters!

So far we've broken the information requirements down into 18 business processes, like personnel, finance and accounting, construction management, etc., and identified the relationships between them. Now we're looking at how we do business in these areas, how we may be doing business in the future, and how the data is involved in conducting that business.

So far we've done this for five areas--construction management, design management, accounting, civil works programs, and policy and guidance--and are now developing some prototype data bases and applications. After field testing, these prototypes will be implemented Corps-wide. The process is expected to be completed in 3-5 years.

The important thing about this plan is that it is the functional users who are developing each of the data bases. This is not something being imposed by the IMS folks. They are helping to facilitate the development, and will be handling the hardware and software acquisitions.

The acquisitions will be extensive. They involve such hardware as a supercomputer, microcomputers (the Corps will have one microcomputer for every four employees by the end of this fiscal year), replacement of the mainframes in the FOA's, and computer-aided drafting and design--as well as such specialized systems as mini-computers for water control of river basins.

The Corps is in the forefront of the Army in automation, and we're ahead of DOD in information planning. Much of our work in the ISMP will form the basis of an Army-wide information modernization program.

Although we're starting with business-type information, our goal is to include technical data under the plan. Computer-Aided Drafting and Design is one example. Initially an automated drafting tool, it will eventually store and interrelate as-built drawings.

Another example--and one that involves the work you do--is the Geographic Information System. This is an information system for storing, retrieving and manipulating technical and economic data about a geographic area--soil, climate, geology, vegetation, demographics, etc.--very useful information for our planners and designers.

IV. REMOTE SENSING

As WRDA '86 has made the need for accurate, timely information more critical, remote sensing is taking on an ever-increasing value. It reduces our planning time, and it enhances the validity of our decisions. We must integrate this data into our way of doing business, just as we do other types of information.

Many things have changed in remote sensing since I addressed this audience in 1979.

Much of the remote sensing research and product development was then being accomplished by the Federal government, specifically NASA, in an effort to foster applications, initiate technology transfer, and broaden the customer base.

During the past 8 years, the technology, applications, and the procedures for managing and analyzing remote sensing data have evolved tremendously from high risk research to a viable commercial product. Since then, NASA has significantly reduced its effort for technology transfer and has placed the responsibility with the users, agencies, and private sector.

Today the private sector is a major entity in the remote sensing business. This is evident in the number of companies providing remote sensing processing services and equipment, many of which are represented here at this symposium. The private sector will be the major source for future remote sensing products to meet our needs. I encourage you to visit and talk with the commercial vendors to exchange ideas and explore ways in which their products need to be developed to assist us in accomplishing our mission.

In 1979, the U.S. Government was the only operator and source for land satellite remote sensing data. Today there are multiple sources, including the private sector and foreign countries. Because the Corps uses remote sensing data operationally, we need the flexibility and the responsiveness of the commercial system.

What has impressed me the most is how the Corps' remote sensing program has evolved since 1979. I have always felt the Corps is a leader in the operational application of remote sensing technology. At that time, it required costly mainframe computers and time --lots of time-- to process remote sensing imagery.

In 1979, three new technologies were emerging: digital satellite data, microcomputers, and geographical information systems. Our laboratories were working with the field offices to test and develop a method to use and integrate these technologies. Digital satellite data has changed our concept of collecting and managing remote sensing data. This format has provided us the ability to integrate remote sensing data with other types of information as data for numerical modeling.

The Corps has begun to operationally apply GIS's, and thus we need to review the role of GIS's in our future. I have appointed Dr. William Klesch in September as my Special Assistant for Geographic Information Systems. Bill's mission is to assess the total Corps effort in developing data bases and methods of computerized analysis, including GIS. He is doing this in close coordination with IM so that GIS will develop as an integral of the Corporate System Plan. Bill is participating in this symposium, and I encourage you to talk with him and express your ideas about the future role of remote sensing and GIS.

The Corps has done well in using these technologies, which is demonstrated by the many papers and poster sessions here at this symposium. Today, several Corps offices have in-house micro or mini computer processing capabilities, which are used in conjunction with the power of the geographic information system.

Remote sensing technologies have always been difficult to integrate into the Corps business process. Because this data is applicable to planning, engineering, construction, and operation missions of the Corps, there is not a traditional stovepipe for technology transfer.

Nevertheless, we have been successful in technology transfer, for which I must commend the persistence and determination of individual people in the Corps.

The level of expertise and use of these technologies, however, varies widely from Division to Division, District to District, and discipline to discipline. I will encourage upper level management to consider these technologies, but you must present the case of how these technologies can help you--and particularly your colleagues--do the job better, faster, and cheaper.

You have here at this symposium the collective knowledge of the Corps experience with these technologies. Case histories will present the good and bad, and help us make wise use of this technology. Talk to the people, take home with you this wealth of knowledge, apply it to your mission.

What must we do in the future? I have provided you with the framework of the Corps future business processes, but you are the ones that will make it happen.

We must think of remote sensing as an information system, and integrate this data with the Corps Corporate Information System Plan and business processes. This will not be easy, but the time has come, with the rapid advancement in data capture, microcomputers, telecommunication, and information delivery and distribution systems, that it will be feasible.

Today, the Corps needs to be as efficient, professional, innovative, quality conscious, and productive as any time in its history. You have a tool that is of prime importance in making this happen.

I am counting on you to bring the best of this technology to the accomplishment of our mission.

SPACE STATION - POLAR PLATFORMS OPERATIONAL INSTRUMENTATION

Bruce H. Needham
NOAA/NESDIS
Polar Platform Payload Manager

SUMMARY:

In the mid-1990's, the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) will combine efforts to launch two Polar Platforms in conjuction with the Space Station mission. NASA's Polar Platform, scheduled for launch in 1994, followed by the ESA platform in 1995, offers the capability to provide the scientific, engineering, and commercial community with a permanent, servicable polar orbiting platform. This system, in addition to its scientific value, is fiscally sound, and will provide the entire world with a system that will ensure the continuous collection and dissemination of environmental data and information from space for decades into the future.

The National Oceanic and Atmospheric Administration (NOAA), which operates the US civiliam operational environmental satellite system through its National Environmental Satellite, Data, and Information Service (NESDIS), is firmly committed to the concept of utilization of the Space Station - Polar Platforms in the mid-1990s and beyond. NOAA is committing itself to the Polar Platforms by following the NOAA-K, L, M series of polar orbiting satellites with the placement of its operational payloads on both the NASA and ESA platforms.

The objective of this presentation will be to describe the current status of planning for the acceptance, design, construction, and integration of the NOAA operational payload into the NASA and ESA Platforms, and to describe the follow-on and upgraded instrumentation that NOAA, and the International community is proposing for this project.

NOAAs current proposed instrument complement includes:

- the Advanced Medium Resolution Imagery Radiometer [AMRIR] which will replace the current AVHRR and HIRS with an 11 channel instrument with 500 meter resolution;
- the Global Ozone Monitoring Radiometer [GOMR] which will replace the current SBUV sensors;
- an Earth Radiation Budget Instrument [ERBI] which will be an upgraded version of the ERBE flown on Nimbus and the NOAA-9 and 10 satellites;
- the Advanced Microwave Sounding Units - A & B which will be a follow-on to the units on K,L,M which replaced the MSU and SSU;
- an Altimeter similar to that flown on GEOSAT/NROSS;
- a Scatterometer similar to that to be flown on NROSS;
- a Space Environment Monitor package substantially upgraded

from that flown on K,L,M;

- the ARGOS Data Collection and Location System; and,
- a Search and Rescue System.

In addition to the above, three of which are contributions in whole or in part by the international community, additional sensors are being proposed by the countries of Australia (a Spectrograph for Oxygen A-band, and a Cloud Size Analyser), Canada (a Brewer Ozone Spectrophotometer); the Federal Republic of Germany (a Michelson Interferometer for Passive Atmospheric Soundings, a Millimeter Wave Atmospheric Sounder, a Conical Scanning Radiometer, and an Aerosol Lidar Experiment); Italy (an Advanced Microwave Imaging Radiometer, and an Ocean Color Monitor); Japan (an Ocean Color and Temperature Sounder, an Advanced Microwave Scanning Radiometer, an X-band Synthetic Aperture Radar, a Scatterometer, an Altimeter, and an Intermediate Thermal Infrared Instrument); and the United Kingdom and Australia (an Along-Track Scanning Radiometer).

SESSION I

GOES DATA COLLECTION SYSTEM

John Nichols

U.S. Army Corps of Engineers
Water Resources Support Center, Ft. Belvoir, VA.

ABSTRACT

The Corps of Engineers is a major user of the Geostationary Operational Environmental Satellite (GOES) Data Collection System (DCS) operated by NOAAs. Corps Water Control Managers currently have the responsibility for operating over 650 projects nationwide for multiple purposes including flood control, navigation and hydroelectric power generation. The collection of timely and accurate information on a wide variety of environmental and operational data from field sites is essential for the effective regulation of these projects. The GOES DCS has proven to be a reliable cost effective method of collecting this data. This paper will describe the number of data collection platforms deployed, where they are located, the different types being used, the number of direct readout ground stations operated by the Corps and possible future Corps uses of the DCS.

MEASUREMENT AND PREDICTION OF BANK EROSION AT ARCHAEOLOGICAL SITES ON CORPS OF ENGINEERS RESERVOIRS USING SEQUENTIAL AERIAL PHOTOGRAPHS

James Ian Ebert
Eileen Camilli
LuAnn Wandsnider

Ebert & Associates
Albuquerque, New Mexico

James J. Hester

U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

ABSTRACT*

Research methods for measuring and predicting impacts to archeological sites and materials caused by reservoir shoreline erosion are currently being developed by Ebert and Associates and the U. S. Army Engineer Waterways Experiment Station. These methods use sequential, historical aerial photographs, and have been tested at twelve large, significant, and erosionally threatened archeological sites along the banks of Corps of Engineers reservoirs on the middle Missouri River. The results of this experiment research indicate that extant historical aerial photographs constitute an ideal -- and perhaps our only -- data source for making high-resolution measurements of such erosional impacts over time. These measurements permit: 1) the documenting of archeological site erosion, 2) the prioritization of sites that require immediate preservation or other management strategies and 3) the modeling of bank erosional processes in general. In this paper, methods developed and conclusions reached are summarized, and a number of observations concerning erosion rates and their causes at the study sites are detailed.

RESEARCH GOALS

Archeological sites in areas to be inundated by reservoir construction are routinely discovered through archeological surface survey, and under historic preservation law adverse effects to those sites are required to be mitigated through recording and excavation. However those sites with cultural value above maximum pool elevations are not routinely treated in this manner.

Permission was granted by the Chief of Engineers to publish this information.

Nonetheless, such sites, when they are situated on Federal property, must be managed equally, according to the procedures specified in historic preservation legislation and regulations.

In many parts of the country, due to patterns of past land use, many of the largest and most significant prehistoric and historic archeological sites are located on terraces immediately above the maximum pool levels of reservoirs. A striking example of this is found at Corps of Engineers reservoirs along the Middle Missouri River in North Dakota, South Dakota and Nebraska. In this area hundreds of large and significant village sites dating from the Middle Missouri (AD 900 - AD 1400) and Coalescent (AD 1400 - AD 1860) Traditions are located above the floodplain of the Missouri River (Lehmer 1971). These sites comprise the bulk of the archeological evidence of the lifeways of the past peoples of a large portion of the Great Plains. Especially important is the fact that these sites represent not only the type sites but the majority of all sites known for these cultural periods. Unfortunately, many such sites are presently threatened by bank erosion. Such erosional problems were not anticipated when the reservoirs were built, consequently no measures have been developed to cope with them. However if current rates of site loss continue, we face the real possibility of the loss of the majority of the cultural resources within this entire region.

The research which we report upon here was designed to facilitate a more complete understanding of bank erosion and its causes at these reservoirs.

Specifically, the goals of this research are to explore the utility of photointerpretation and measurement of bank erosion using sequential, historical aerial photographs; to empirically document that bank erosion is threatening reservoir-side archeological sites; to model natural and cultural factors affecting differential rates of erosion between and within such sites, to predict future bank erosion; and to compile priority lists for the treatment of such sites as part of overall project management plans. Hopefully, such methods can then be applied at other Corps of Engineers reservoirs throughout the country.

Aerial photographs have been employed by archeological researchers studying the cultures along the Missouri River, their use was primarily for the discovery and mapping of archeological sites. Our current research interest is in the extraction of quantitative data relevant to bank erosion, and as such represents a new direction in the use of archeological remote sensing in the region.

The Cultural Resources Preservation program within the Environmental Impact Research Program (EIRP) Environmental Laboratory, WES; in consultation with the Corps' Omaha District archeologists, had recognized that significant portions of the archeological record along Middle Missouri River reservoir shorelines was being threatened, that the rate and nature of such threats was not fully understood, and that quantitative studies to answer this lack of data were sorely needed. The overall programmatic interest of the site preservation program was to identify rates of erosionally caused site loss and then utilize this information in the planning and implementation of site preservation options.

The work described here springs from a contract with the US Army Corps of Engineers entitled "Mapping and Prediction of the Erosion of Archeological Sediments at Reservoirs Along the Middle Missouri River with Sequential Historical Aerial Photographs." It was initiated in July 1986 by Ebert and Associates, an Albuquerque firm involved in Anthropological, Archaeological, and Forensic Remote Sensing and Photogrammetry, in response to a request for proposals published in the Broad Agency Announcement by the U. S. Army Engineer Waterways Experiment Station, Vicksburg, Ms.

PREVIOUS APPLICATIONS OF AERIAL PHOTOGRAPHS IN MAPPING BANK AND SHORELINE EROSION

Aerial photographs have been used by many scientists from various fields for mapping shorelines and their characteristics, for example, changes along seacoasts (Civco et al 1986; Shabica et al 1984) and reservoirs (Dolan et al 1978, 1979, 1980; Gatto and Doe 1983, 1987). Recently, archeologists have also shown interest in the applications of aerial photographs for measuring bank and other erosion at archeological sites (Corbyn 1984; Ebert 1984; Ebert and Gutierrez 1981; Ebert and Lyons 1986, Grady 1986).

Shoreline retreat studies carried out by Gatto and Doe (1983, 1987) based on measurements from historical aerial photographs had mixed results. These authors attributed such problems as being due to inaccuracies inherent in aerial photographic measurement such as interpretive overlay line width, radial displacement, relief and tilt distortions, scale variations, problems with ground control, and "human errors when making the measurements" (Gatto and Doe 1983:12). Other authors (Dolan et al 1980), however, have calculated their shoreline measurement error to be approximately 1.25m using 1:5000 scale photographs, a relatively small error compared to most annual shoreline erosion rates.

Even while questioning the value of aerial photogrammetry to supply useful measurements, however, Gatto and Doe (1983, 1987) contend that their study revealed a "common-sense" conclusion regarding reservoir bank erosion -- that it occurs quickly - immediately after reservoir filling, and then becomes less rapid and of less concern within a few years. Archeological remains (and other resources) along reservoir banks, then, while threatened at first, are less endangered very quickly. Results of our study, described below, suggest that this may not, in fact, be the case.

DATA COLLECTION METHODS, ANALYSIS, AND PRELIMINARY RESULTS

Analysis of the phenomenon of bank and site erosion has been structured at different levels in this project. This analysis has focused on: (a) the site, a more or less arbitrarily defined unit based on the extent of cultural features like housepits or palisade ditches; (b) bank erosion and variability in that erosion within site "areas"- a 2km long shoreline section with the site at its center; and (c) bank erosion, and its predictability, from the perspective of the overall Middle Missouri River system. Data collection methods that incorporate different kinds of photointerpretation appropriate to each of these three levels were designed and executed as described below. Some of our preliminary results are also discussed for each.

Aerial Photographs and Photointerpretation

Twelve erosionally endangered sites recommended by the U. S. Army Corps of Engineer Omaha District were selected for study (Figure 1). These sites contain lithic and ceramic remains indicative of intensive recurring occupation during the Archaic, Woodland and Plains Village periods. The Plains Village and later Post-Contact villages also contain earthlodges, and some of these sites are fortified with bastions and ditches.

Aerial photographs were obtained from a number of government repositories. The oldest photographs available for study are from the National

Figure 1. Location of erosionally endangered sites included in this stud

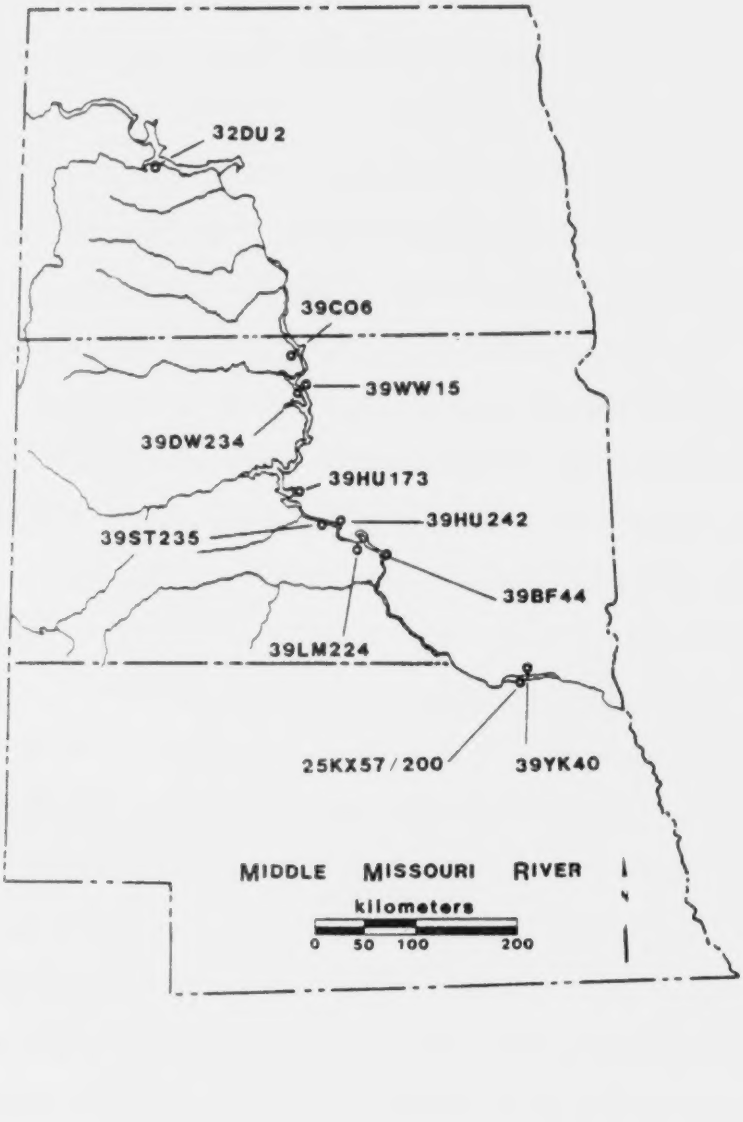

32DU 2
39CO6
39WW15
39DW234
39HU173
39HU242
39ST235
39BF44
39LM224
25KX57/200
39YK40
MIDDLE MISSOURI RIVER
kilometers
0
50
100
200

Table 1. Summary of aerial photographic coverage for Middle Missouri sites included in this study.

SMITHSONIAN NUMBER	SITE NAME	DATES OF COVERAGE EARLIEST-LATEST	NUMBER OF OVERFLIGHTS	RANGE OF SCALES LARGE/SMALL (1:X,000)
25KX57/200	---------	1938-1984	22	20 129
32DU2	Midipadi Butte	1938-1985	17	20 80
39BF44	USDA	1938-1986	16	20 80
39CO6	Jake White Bull	1938-1986	14	20 80
39DW234	Molstad	1938-1986	17	20 123
39HU173	---------	1939-1986	21	16 124
39HU242	Whistling Elk	1939-1984	20	20 126
39LM224	Cable	1938-1984	18	20 126
39ST235	Stoney Point	1939-1984	18	20 126
39WW15	Travis II	1938-1986	12	20 80
39YK40	Jazz and Jill	1938-1985	28	12 128

Archives; these date to the late 1930's and show "baseline", prereservoir erosion. Contact prints spanning the year 1949 through the present were obtained from the US Geological Survey and the Agricultural Stabilization and Conservation Service. A final major source of aerial photographs was the U. S. Army Corps of Engineer Omaha District Office, which provided large scale aerial photographs dating from the early 1970's to the present. The coverage obtained for each site is summarized in Table 1.

Using procedures outlined below, stereo photointerpretation of aerial photographs focused on criteria which could best distinguish bank from beach from waterline. On black and white photos, abrupt changes in tone are often apparent. Beaches appear very light-toned, banks are more greyish, and the reservoir appears almost black.

Measuring Site Erosion

At the largest and most specific spatial scale, the study of bank erosion was focused on the site itself. An electronic enlargement/enhancement process was developed to examine the immediate area of the site. These areas were enlarged and electronically edge- and contrast-enhanced using an analog video enhancement system at Ebert and Associates' laboratory in Albuquerque. The results of these analyses were photographed from video screens, and then further enlarged by projection onto base maps at a scale of about 1:1000. Site boundaries were defined using photointerpretable indications of cultural features.

Bank position shown on each sequential aerial photo for each site area was then marked on the base maps (Figure 2), and the area of each site remaining at each date was measured digitally. As seen in Figure 3, the change in site area through time is linear although the slope of that line is

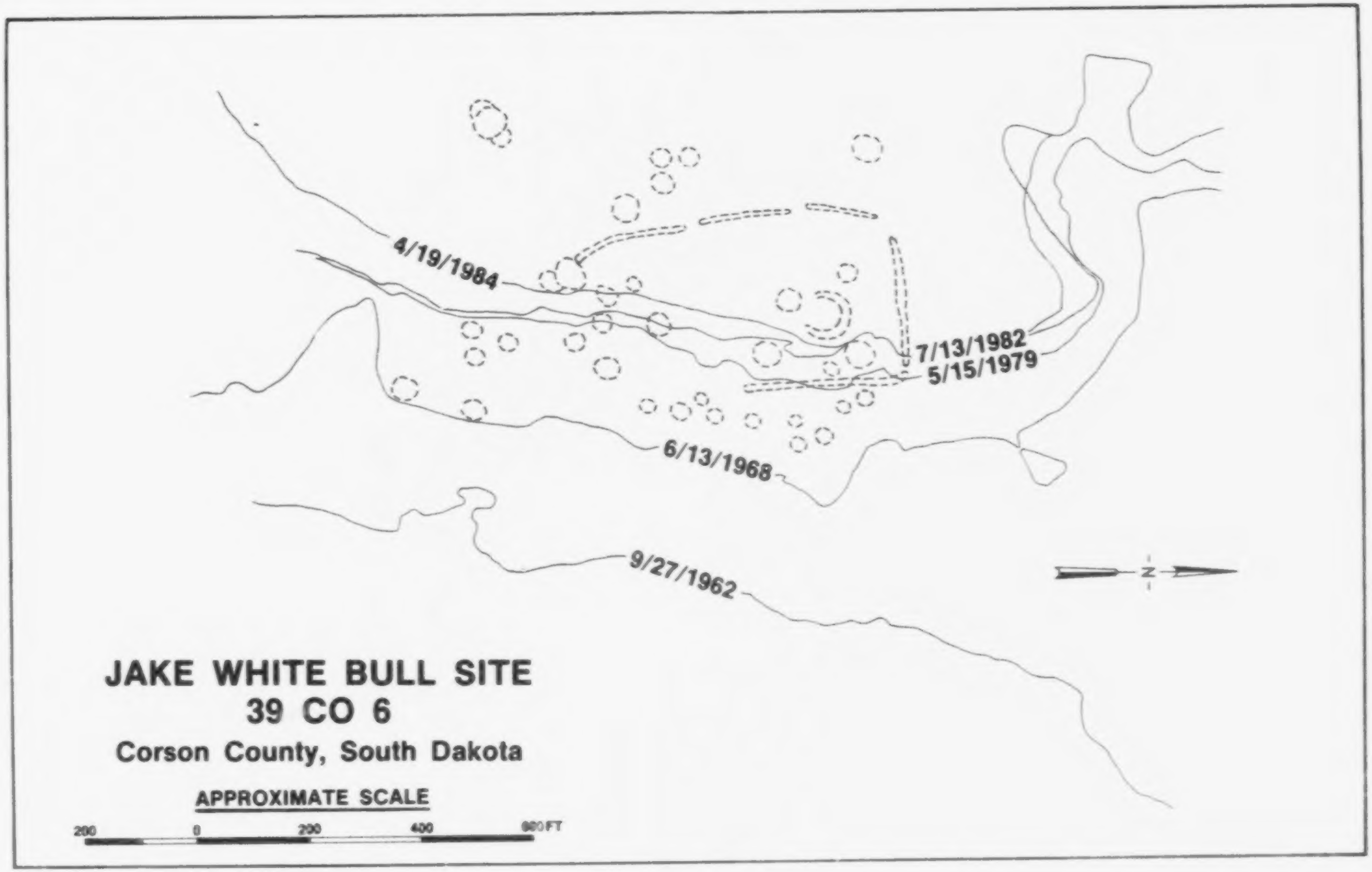
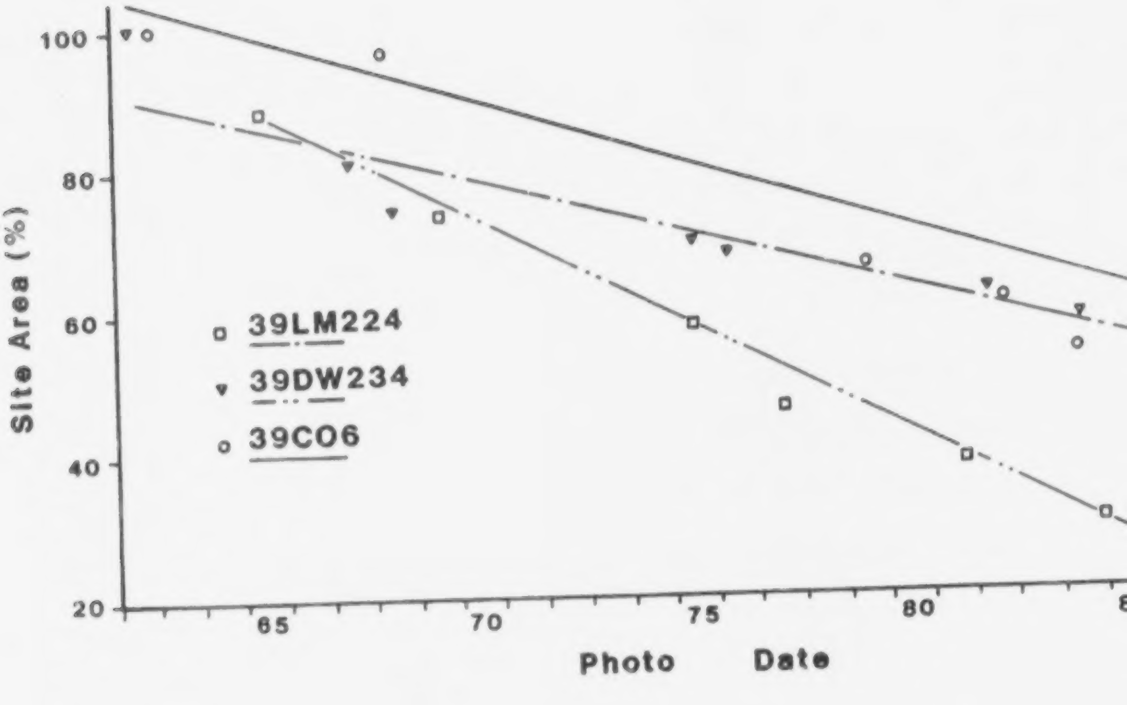

JAKE WHITE BULL SITE
39 CO 6
Corson County, South Dakota
APPROXIMATE SCALE
200
0
200
400
600 FT
N
4/19/1984
7/13/1982
5/15/1979
6/13/1968
9/27/1962

Figure 2. Photointerpreted bank location at site 39CO6 through time

Figure 3. Site area through time for sites 39DW234, 39CO6, and 39LM224.



different for different sites. These figures were subjected to a regression analysis and equations for each site-area decay curve were calculated.

One observation made during statistical analysis is that a linear regression model fits the decay curves very well. This tendency suggests one of two possibilities. The first of these is that erosion rates are relatively constant through time, although location dependent. Thus, it may be far longer than often assumed (see Gatto and Doe 1983) until the "deceleration" of bank erosion on the order of several hundred years. The second possibility is that while a sigmoidal model, in which initial erosion rates are high and then progressively decrease (Gatto and Doe 1983), may describe the behavior of the erosion of banks through time, the photo dates available to us allow documentation of only the initial, near-linear part of the model. With either possibility, however, the study sites, and other sites along the banks at Missouri River reservoirs, clearly are being destroyed at a predictable rate by bank erosion. For example, some specific sites will be entirely lost within the next 10 to 30 years (Table 2).

Interestingly, additional cultural features including earth lodge depressions and palisade ditches were found at several sites. Even though these were unmentioned in the state and federal site reports for those sites. This does not indicate "inadequate" surface survey, but simply underlines the fact that different sorts of cultural evidence can be identified when one looks for it in different ways. Illustrative of this is the fact that each year and emulsion type of aerial photograph revealed different evidence; parts of a palisade can be seen in some years, a few housepits another, and travois trails on yet another set of photos. In some cases, each of twenty or more sets of aerial photographs showed additional evidence. To our knowledge, no

Table 2. Extinction dates predicted by regression equations.

Site	Extinction Date
39LM224	March 1, 1994
39LM234	May 24, 2019
39CO6	April 8, 2009

photointerpretive survey has ever made use of so many complementary sets of aerial photos of single sites in this manner.

Measuring Bank Erosion along 2km Site Area Segments

At a somewhat smaller scale, bank erosion along 2km segments of shoreline centered on sites was measured. At this scale of analysis, the differential erodability of the site -- compared to non-site sediments -- may be examined.

As a first step 1:10,000 scale base maps were constructed by photo-enlarging 1:24,000 scale 7.5-minute USGS topographic quadrangles. A 2km x 2km quadrat centered on each site permitted projective enlargement from aerial photos with scales of 1:40,000 and larger to these base maps, while keeping the base map format (about 50cm x 50cm) physically manageable. Stable film positive masters were then made onto which were drafted shoreline and erosional zone data. The map image was screened to 50% intensity so that subsequent information drafted onto the frosted mylar would be easily distinguishable from the base map information.

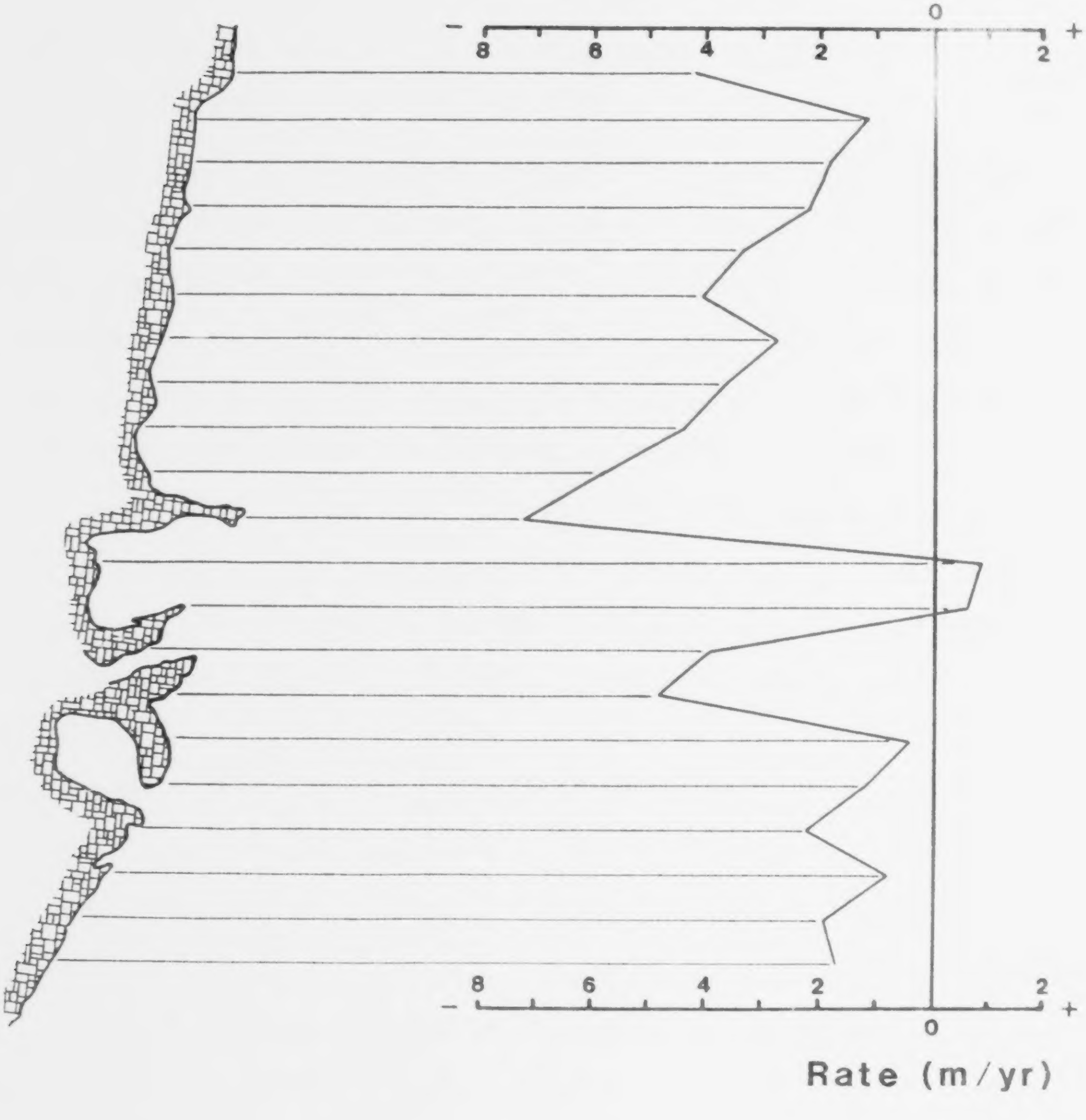
Photointerpretation methods

1. All photos within the historical sequence of photos of each site were first inspected for (a) site specific manifestations of beach, bank and waterline, and (b) the positions of control points on both the photos and the base map.
2. Identification of control points common to both photos and base map that could be noted and marked at each scale.
3. Site specific photointerpretive keys were developed for bank, beach and other erosional zones.

4. The aerial photographs were photointerpreted at 6X magnification using a mirror stereoscope, and transparent acetate overlays of bank and beach position were drafted for each stereo pair.
5. Simplified mylar base maps with control points were drafted.
6. The acetate overlays were enlarged and scale-rectified using an optical projector in order to transfer the bank and beach locations to the mylar overlays.
7. A 1:10,000-scale stable film baseline map was prepared using the earliest photo of the site on which the reservoir was filled. Transects were then drafted at 100m intervals along the waterline, oriented perpendicular to the gradient or slope just inland from the waterline. These transects served as objectively determined points along which bank retreat could be measured on successive photos.
8. Using digital calipers, the amount of displacement between the baseline (earliest) location of the bank and the position of the bank interpreted from each stereo pair at each of 21 transects (1km on each side of the center of the site) was measured; the gradient and aspect of the bank at each transect was also recorded.
9. These measurements were then entered into a computer and erosion rates fo each transect and between each sequential pair of photo dates were calculated

Analysis of the transect data for each site shows that there is a high degree of variability in erosion rates along a specific stretch of bank. For example, at 25KX57 and 25KX200, we observed both high and low erosion rates and moderate aggradation rates. These different rates may be correlated with differing topographic situations along the bank that, at the time of the creation of the reservoir, formed either peninsulas that protruded into the reservoir, or more sheltered bays (Figure 4).

Figure 4. Mean erosion (-) and aggradation (+) rates calculated for transects at site 25KX57/200.



Determination of Measurement Accuracy

A number of sources of possible inaccuracy or imprecision which could influence the measurements of bank position can be identified. One of our first fears was that the thickness of the lines drafted on transparent photo overlays might be an error introducing factor. After a number of very frustrating attempts at using 6x0 Rapidograph nibs, we realized that the problem was really "artificial" -- if the edge of a drafted line is used to define the bank position, line thickness is of no concern. Another more significant problems is the parallax displacement inherent in aerial photographs. To correct this we used frames in which the portion of the bank being interpreted was near the center of the photo. In any case, most of the banklines interpreted were relatively level along their length, making parallax displacement uniform at each site. An undoubtedly far greater problem is presented by variation in the "steadiness" of the interpreter's hand. The only solution we found for this problem was to draft interpretive overlays during short sessions, and to exercise the greatest of care at all stages of interpretation, overlay drafting, overlay enlargement, and measurement.

At present, no purely empirical method of assessing the accuracy of the measurements obtained has been devised. Past bank positions are, of course, no longer there to measure, so "field checking" is not possible. Topographic maps made prior to reservoir filling are of substantially lower resolution than the measurements being made here, so comparisons with these are not meaningful either.

Fieldwork at eight of the twelve sites was carried out in October of 1987. Those field activities included mapping the bankline at those sites on the date of the site visit using electronic distance measurement (EDM) equipment. Perhaps the best assessment of the accuracy of the aerial photographic measurements will ultimately result from comparing these ground measurements with predictions of where the banks should have been on those dates, based on prior measurements. Although this has not yet been done, we observed nothing during fieldwork that would change our previous conclusions concerning the rates of erosion in progress.

GENERAL SYSTEMIC TRENDS IN BANK EROSION

Table 3 summarizes overall erosion rates observed at the 12 study sites. These rates are calculated as the mean of all transect erosion rates derived from the difference between the bank position on the first and last photo dates divided by the amount of elapsed time. As seen in Table 3, there are several groups of rates. Site 39DW234 manifests the highest overall average erosion rate (7.32 m/yr). Sites 39HU173 and 39YK40 show the lowest overall erosion with rates less than 0.6 m/yr. All other sites range between 1.8 and 3.08 m/yr. These rates are consistent with and in some cases higher than many previously reported shoreline erosion rates based on aerial photogrammetry (Gatto and Doe 1983, 1987; Millsop 1985).

CONCLUSIONS AND OBSERVATIONS

The research we have described in this paper is scheduled to be completed in March 1988. At this point in time, however, there are some general and (we feel) interesting conclusions that can be drawn concerning the methods developed and used in this research.

First, Archeologically relevant bank erosion can, in fact, be measured using sequential aerial photographs. Although accuracy verification has not

Table 3. Overall erosion rates for Middle Missouri River Sites included in study.

Site	Number of Photos	Photo Date First	Photo Date Last	Erosion Rate Mean	Erosion Rate STD
39DW234	8	9-27-62	5-30-86	7.32	4.51
39CO6	3	6-13-68	7-31-82	3.08	2.22
39LM224	4	6-21-65	8-12-77	2.95	1.59
39BF44	7	8-5-55	5-31-86	2.59	0.90
32DU2	3	5-25-66	10-18-85	2.44	1.28
25KX57/200	6	6-18-57	9-8-78	2.37	2.45
39HU242	5	6-17-68	6-3-83	2.33	1.09
39ST235	6	6-17-68	6-3-83	2.23	0.49
39WW15	5	7-25-70	5-30-86	1.82	0.85
39HU173	4	6-18-68	5-31-86	0.60	0.72
39YK40	8	6-23-56	5-23-83	0.41	0.60

yet been completed, our belief is that some previously cited accuracy problems (for instance, line width) are "non-problems." In fact the accuracy and precision of measurements may well be quite high, on the order of a few tens of centimeters on the ground using larger-scale photographs.

It is also apparent that mean bank erosion rates at the Middle Missouri River study sites are high enough to be of immediate concern to all archeologists, and especially those charged with their management since large portions of these significant archeological sites are rapidly disappearing.

Bank erosion rates are, at the same time, *extremely variable even within sites*. This variability may be the result of measurable natural factors, and may therefore be predictable and thus provide a realistic basis for prioritizing cultural resource management efforts. Some of this variability is demonstrably due to variations in fetch, aspect of the shore, and the shore's slope. Field observations indicate that one of the most important factors, however, may simply be the height of the bank and thus the amount of sediment that must be removed by erosional processes.

Measures of the erosion of site areas and the projection of site "extinction dates" suggests that bank erosion is a linear phenomenon, and either has not "leveled off" in the 20-40 years following reservoir filling, or perhaps will not level off. Bank erosion is not, therefore, a matter of diminishing concern.

Finally, what we believe to be a very important conclusion was noted during fieldwork in the fall of 1987, and illustrates that erosional impacts are affected not only by natural factors, but perhaps just as much by past and by contemporary cultural processes as well. During our fieldwork, we observed that "pothunting," the illegal recreational looting of archeological sites, appeared to influence erosion rates at the study sites. Banks appear to be eroding away at higher rates, recently at least, in those portions of sites where the most pothunting is going on. This factor might be seen as "complicating" the prediction of bank retreat, but at the same time it is somewhat encouraging because it means that we might be able to do something to reduce bank retreat rates as well.

At middle Missouri River reservoirs, little attempt has been made to curtail illegal site looting due in part to the lack of Corps personnel and the vastness of those reservoirs. In addition we can anticipate arguments that would almost certainly be used by defense attorneys during looters' trials -- that the banks (and sites) are eroding anyway, and that the Corps and the archeologists aren't doing anything to save them, so why not let people have fun collecting sherds, bones and arrow points on weekends? This argument is seriously diminished if the mechanical disturbance caused by looting is actually causing an increase in bank erosion, and this observation may present a very immediate reason to increase efforts at curtailing illegal excavations at reservoir-side archeological sites.

REFERENCES

Civco, Daniel L., William C. Kennard, and Michael W. Lefor

1986 Changes in Connecticut Salt-Marsh Vegetation as Revealed by Historical Aerial Photographs and Computer-Assisted Cartographics. Environmental Management 10(2):229-239.

Corbyn, Ronald C.

1984 National Historic Landmark Status Report, 1984: Fort Hall, Idaho. Manuscript on file at Interagency Archeological Services, National Park Service, San Francisco.

Dolan, Robert, Bruce Hayden, and Jeffrey Heywood

1978 A New Photogrammetric Method for Determining Shoreline Erosion. Coastal Engineering 2:21-39.

Dolan, Robert, Bruce P. Hayden, Paul May, and Suzette May

1980 The Reliability of Shoreline Change Measurements from Aerial Photographs. Shore and Beach, October 1980, pp. 22-29.

Dolan, Robert, Bruce Hayden, Cary Rea, and Jeffrey Haywood

1979 Shoreline Erosion Rates along the middle Atlantic coast of the United States. Geology 7:602-606.

Ebert, James I.

1984 Remote Sensing Applications in Archeology. In Advances in Archeological Method and Theory, Vol. 7, edited by Michael B. Schiffer. Academic Press, New York.

Ebert, James I. and Alberto A. Gutierrez

1981 Remote Sensing of Geomorphological Factors Affecting the Visibility of Archaeological Materials. In Technical Papers of the American Society of Photogrammetry, 47th Annual Meeting, Washington, DC, pp. 226-236. American Society of Photogrammetry, Falls Church, VA.

Ebert, James I. and Thomas R. Lyons

1986 Measuring Archeological Site Erosion with Aerial Photographs. Interagency Archeological Services, National Park Se San Francisco. In press.

Gatto, Lawrence W. and William W. Doe III

1983 Historical Bank Recession at Selected Sites Along Corps of Engineers Reservoirs. US Army Corps of Engineers/CRREL S Report 83-30.

1987 Bank Conditions and Erosion Along Selected Reservoirs. Environmental Geology and Water Sciences 9(3):143-154.

Grady, James

1986 A Photointerpretive Evaluation of Aerial Photography of Mud Springs Pueblo, Cortez, Colorado. Report prepared for the U. Engineer Waterways Experiment Station, Vicksburg, Ms. Under Purcha no. DACW 39-86-M-1155, 27 pp.

ITEK Corporation [Alexandria, VA]

1965a Archaeological Photointerpretations of the Brule-Crow Creek Indian Reservation Area, South Dakota. Manuscript, on file at the Midwest Archeological Center, National Park Service, Lincoln, NE.

1965b Archaeological Photointerpretation. Manuscript on file at the Midwest Archeological Center, National Park Service, Lincoln, NE.

Lehmer, Donald J.

1971 Introduction to Middle Missouri Archeology. National Park Service, USDI, Washington, DC.

Millsop, Mark D.

1985 A Quantitative Analysis of Shoreline Erosion Processes, Lake Sakakawea, North Dakota. M.A. Thesis, Department of Geology, University of South Dakota, Grand Forks.

Shabica, Stephen V., Robert Dolan, Suzette May, and Paul May

1984 Shoreline Erosion Rates Along Barrier islands of the North Central Gulf of Mexico. Environmental Geology 5(3):115-126.

Wood, W. Raymond, Robert K. Nickel, and David E. Griffin

1984 Remote Sensing: The American Great Plains. Division of Cultural Resources, National Park Service, Washington, DC.

MONITORING AQUATIC MACROPHYTES USING TM DIGITAL DATA

David Johnson

Water Quality Section, Vicksburg District
U.S. Army Corps of Engineers

ABSTRACT

Two Vicksburg District reservoirs in Arkansas are experiencing serv
macrophyte infestations at several swimming beaches, boat ramps and
marinas.

Operations Division, Resource Management Branch has initiated a
many-pronged approach to the management of this problem. Included
program is an attempt to map the extent of the macrophyte beds usi
digital imagery. Macrophytes have been successfully monitored usi
aerial photography; however, the use of satellite imagery is new.
of the TM increased resolution over MSS data, success is likely.
successful, TM imagery will be used to map the extent and progress
the macrophyte beds as well as the success of the management progra

A number of sample areas on the two lakes have been selected. Land
digital data from two different times have been acquired. TM band
be used to differentiate between land and water on each scene. Ba
and 2 will be used for classifying the scenes into zones with and w
macrophytes. A RIPS microcomputer based system will be used for c
data analysis.

The Environmental Protection Agency's Remote Sensing Support of the Clean Water Act's Section 404 Enforcement Activity*

Peter M. Stokely
The Bionetics Corporation
P.O. Box 1575
Vint Hill Farms Station
Warrenton, VA 22186

ABSTRACT

The Environmental Protection Agency (EPA) has long recognized the value of remote sensing support for its various programs. One area in which EPA currently utilizes remote sensing is the Agency's involvement in wetland investigations under Section 404 of the Clean Water Act. Programs at the Advanced Monitoring Systems Division of the Environmental Monitoring Systems Laboratory in Las Vegas, Nevada and its branch, the Environmental Photographic Interpretation Center in Warrenton, Virginia, support Section 404 permit evaluation and enforcement actions.

Historical and current aerial photography represent an accessible and valuable remote sensing data source. Through the use of conventional aerial photographic interpretation techniques and historical aerial photography, valuable information about a wetland site's past natural conditions and man-made influences is available. Current aerial photography provides up-to-date information on site conditions. Through analysis of such photography, a wetland site's existence, visible changes, degradation or destruction, and current condition can be documented and described. The information from the analysis can be used to answer many scientific and regulatory questions that are often asked in Section 404 investigations. Topics of particular interest from a regulatory standpoint include pre-violation site conditions, the violation itself, post-violation conditions and historical comparisons of similar wetlands. In reporting their findings, the EPA's remote sensing laboratories produce aerial photographic enlargements, thematic maps and reports describing wetland site conditions and changes. These products are used routinely in investigations and enforcement of Section 404.

---

*Work performed under Contracts #68-03-3161 and #68-03-3532 for the nvironmental Photographic Interpretation Center, Advanced Monitoring Systems ivision, Environmental Monitoring Systems Laboratory, Las Vegas, NV.

INTRODUCTION

Remote sensing support to the Environmental Protection Agency (EPA) is provided by the Advanced Monitoring Systems Division of the Environmental Monitoring Systems Laboratory in Las Vegas, Nevada and its branch, the Environmental Photographic Interpretation Center (EPIC) in Warrenton, Virginia. This remote sensing support has used a wide range of active and passive airborne and spaceborne sensors to gather data. For more than ten years this has included the analysis and interpretation of historical aeria photography.

Historical aerial photography is a powerful source of spatial and temporal information that has uses in many areas, including natural resourc or environmental management and assessment, regulatory decisions, enforceme and archaeological investigations. In many instances the analysis of historical aerial photography can provide the only objective information available about site conditions at a particular point in time.

Historical aerial photography generally refers to an approximate 50-ye time period of systematic areawide coverages, beginning with the earliest years of routine overflights by the Agricultural Stabilization and Conservation Service (ASCS) during the 1930's. The historical photography utilized most by EPA is that taken by government agencies such as ASCS, the Soil Conservation Service (SCS), the U.S. Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA).

This paper will concentrate on the approach and methodology involved i the interpretation of aerial photography and a discussion of its applicabil to Section 404 wetland investigations.

APPROACH

Wetland investigations under Section 404 may involve officials from th EPA, the Army Corps of Engineers (COE), the Department of Justice (DOJ) and the U.S. Fish and Wildlife Service (FWS). One information source that any all of these agencies may use for the investigation is aerial photography f before, during, or after the wetland alteration. Conventional photointerpretation methods support each investigation in two basic ways -- describing wetland characteristics and documenting human activities, as explained below.

Analysis of Aerial Photography

The analysis is performed by viewing backlit transparencies of aerial photography through stereoscopes. Stereoscopic viewing creates a perceived three-dimensional effect which, when combined with viewing at various magnifications, enables the analyst to identify signatures associated with different features and environmental conditions. The term "signature" refe to a combination of visible characteristics (such as color, tone, shadow, texture, size, shape, pattern and association) which permit a specific obje or condition to be recognized on aerial photography. In addition to the above, specific characteristics such as topographic position, moisture conditions, and vegetative cover enable the experienced wetland imagery analyst to delineate historical wetland areas. Such delineations separate photointerpreted wetland from upland, enabling the areal extent and basic characteristics of wetland vegetation and hydrology to be observed and measured.

The availability of several dates of historical aerial photography of a wetland enables it to be observed in different seasons, thus under different levels of foliage density and moisture conditions. Season, scale and other factors combine to make some photography more suitable than others for wetland delineation purposes. The photo-delineated wetland boundaries from multiple years of coverage can be reviewed as a set to give what the analyst considers the most probable area that would be classified as a wetland using field techniques.

Figures 1 and 2 demonstrate the added information available through studying a wetland area under different moisture and foliage levels. Figure 1 is a late summer photograph (September 10, 1973) and Figure 2 is a late spring photograph (May 7, 1981). At A the difference in the standing water level and vegetation density is readily observable. At C a small wetland area is masked by vegetation and not as apparent in the drier, late summer conditions (Figure 1), as compared to late spring, wet and unvegetated conditions (Figure 2). D and F show the additional watercourse location information available from leaf-off (spring) aerial photography.

Wetland Classification

Once a wetland area has been identified, a wetland classification system can be applied. Wetlands and water bodies are classified in accordance with the methods and nomenclature of the National Wetlands Inventory classification system (Cowardin et al., 1979) and the U.S. Fish and Wildlife Service's paper on the system's conventions for use with aerial photography (FWS, 1986). This classification system is a nationally accepted standard for wetland identification, classification, and mapping, structured around a combination of biological, hydrological and substrate characteristics. Other applicable classification systems may be utilized to meet a specific request; however, use of a widely recognized and accepted classification method is essential in enforcement actions.

Cultural Features

The relationship of certain cultural features to the wetland under investigation is an important factor in 404 violations. Although 404 specifically addresses only "deposition of dredged or fill material," other cultural features such as drainage ditches, canals, plowed fields, and roads are important to wetland scientists because of their potential impacts. Most cultural features and many other indirect effects of man are easily recognized on aerial photography. For example, referring back to Figures 1 and 2, observe the man-made channelized drainage patterns visible at B and the probable extraction operation at E. These can be annotated on enlargements and further described in text.

Wetland filling is usually the most significant of these man-made activities from a regulatory viewpoint. Analysis of aerial photography provides information on the general type of fill, its purpose, areal extent, in some cases its approximate depth, and the time period in which it was placed.

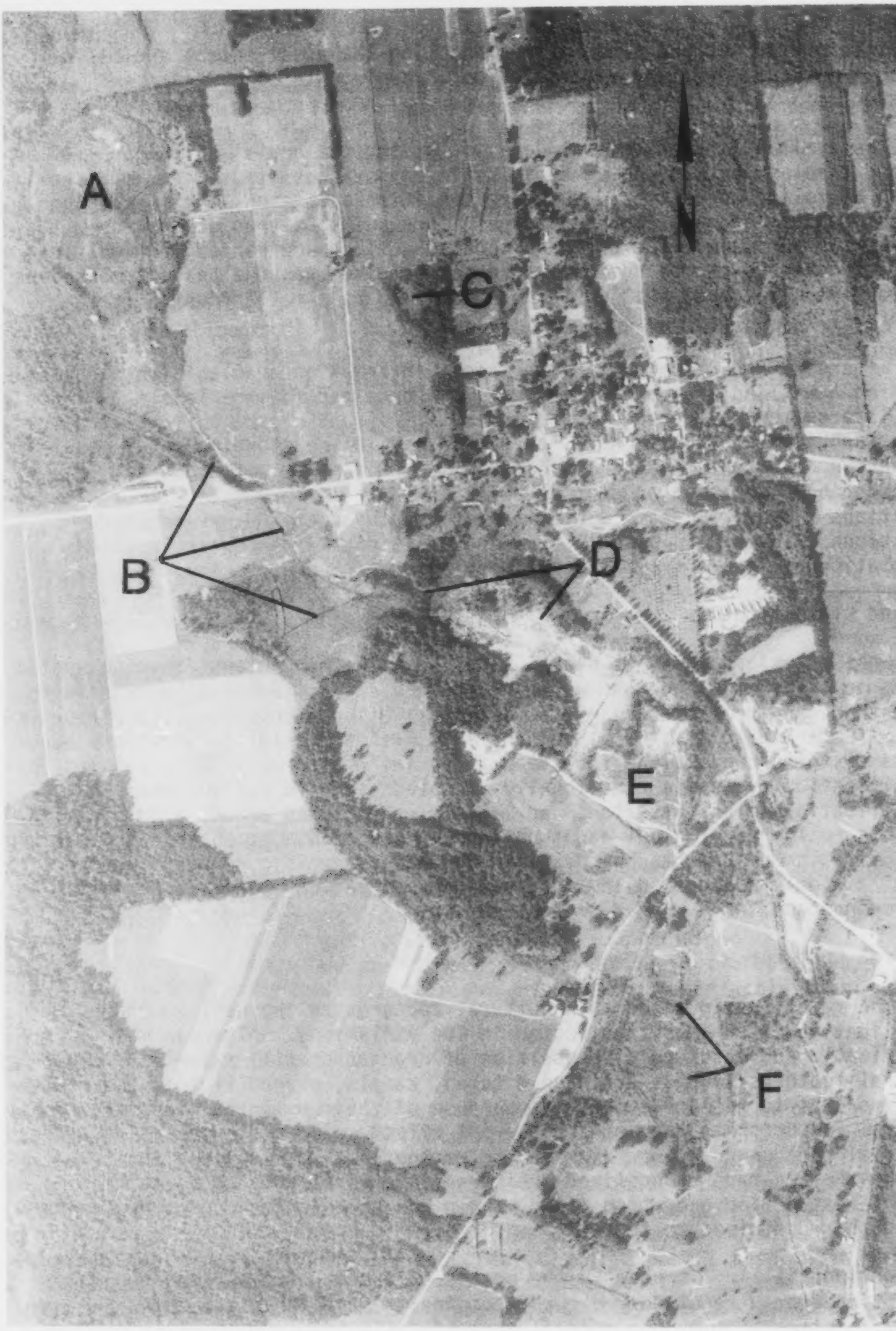


FIGURE 1 SEPTEMBER 10, 1973 APPROX. SCALE 1:11

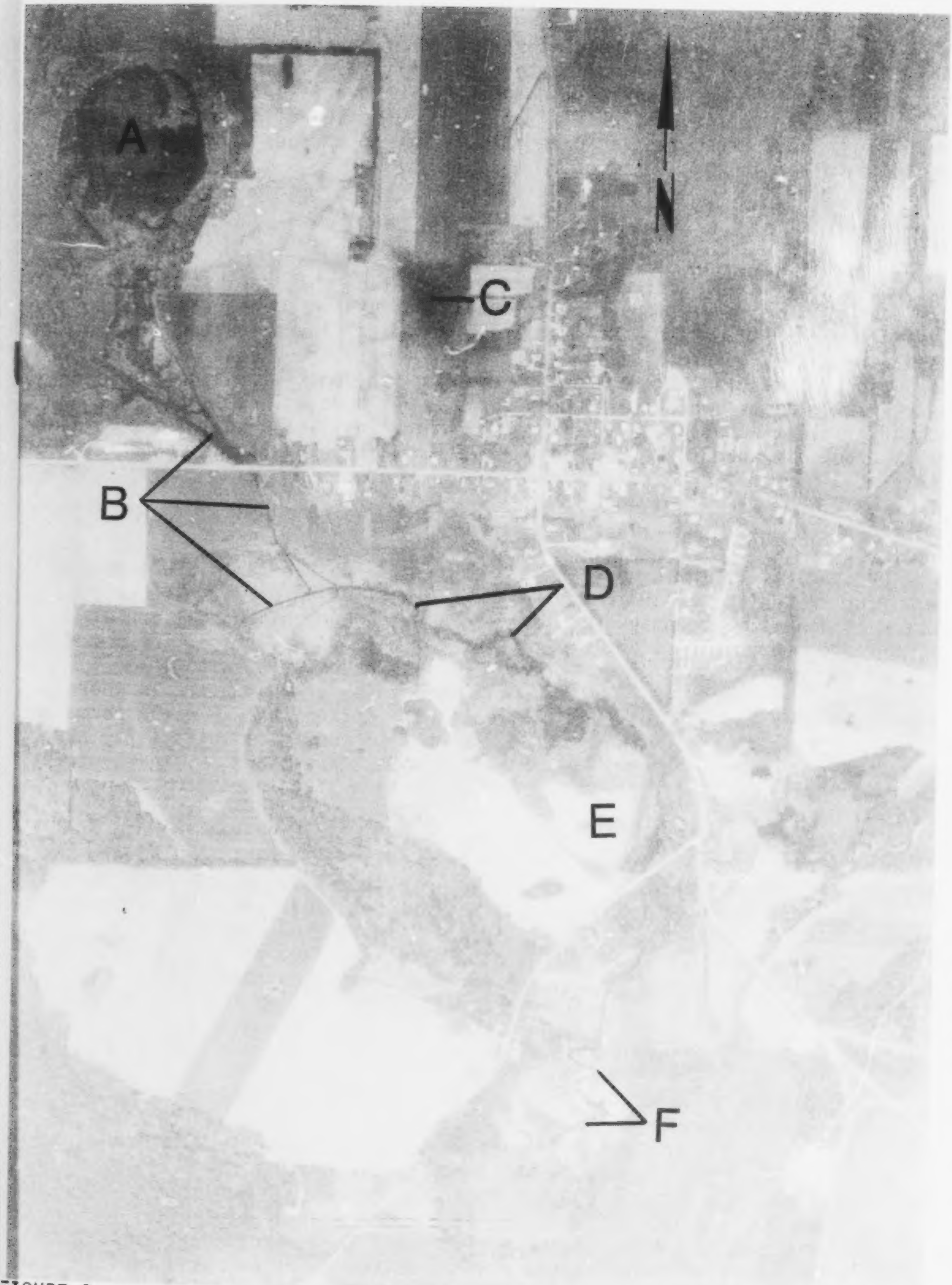


FIGURE 2 MAY 7, 1981 APPROX. SCALE 1:10,000

By utilizing standard photointerpretation techniques, wetlands can be identified, classified, and delineated, and cultural features such as roads canals, and fill areas observed and annotated on overlays to photographic enlargements. The information available from a series of historical aerial photographic coverages then enables the analyst to address many specific issues involved in 404 violations.

DISCUSSION

Each Section 404 activity has different issues that can be addressed through photointerpretation. The following discussion covers some of the issues and questions which could arise in a typical investigation. These issues have been generally categorized as follows: pre-violation site conditions, violation observation and description, post-violation condition and current analysis of historically similar wetlands. These categories do not cover all the potential issues or questions involved with 404 enforceme related activity but serve as logical groupings in which issues connected w historical photographic analysis can be addressed.

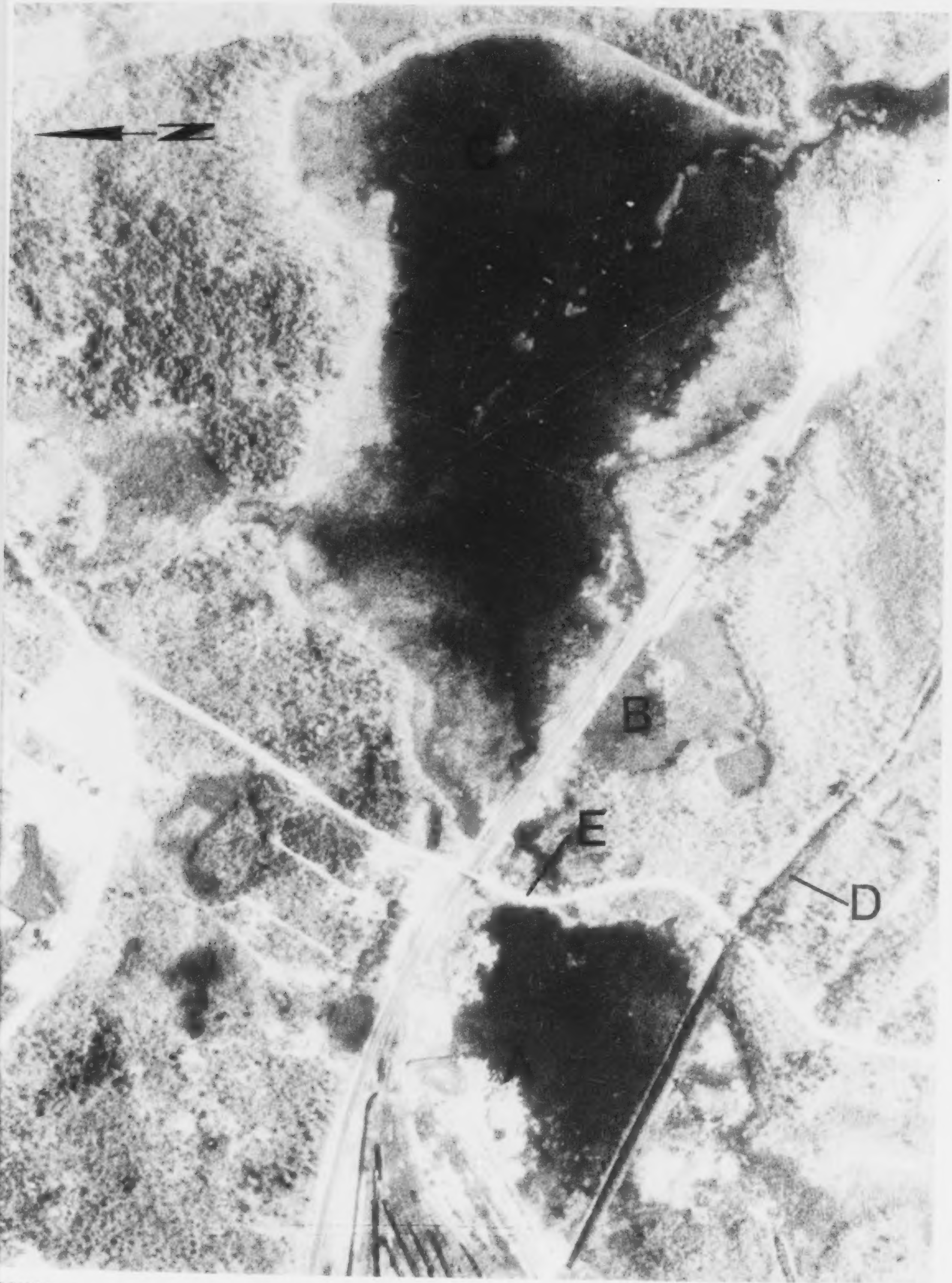
Pre-Violation Site Conditions

One part of determining whether a 404 violation has taken place is verifying the existence and condition of the wetland before its alteration. Some of the most frequently asked questions are: Does historical aerial photography support the identification of the site as a wetland? If so, wh type of wetland? How large is it? What is its association with other wetlands or water bodies? What man-made influences are visible? Is there pre-existing connection to other "waters of the United States" via a perman water body or perennial stream? What is the site condition or activity dur a particular period of ownership? Resolving these questions is important i determining liability for the violation under investigation.

Figures 3, 4 and 5 show the same area over a 43-year time span to illustrate a historical sequence of typical wetland alterations. Figure 3 shows a wetland complex as it appeared in November 1938. A and C are open water wetlands with emergent and aquatic bed vegetation. B is an emergent marsh. Cultural features that have impacted the wetland complex are a railroad fill that separates wetland area B from wetland area C, a canal at and road filling at E. Overall, the 1938 photography establishes clearly t wetlands existed onsite before site alterations began.

Violation Observation and Description

Depending on the dates of photography available, an alteration or encroachment event may be observed in progress or shortly after completion, allowing the analyst to glean information about the type of encroachment. the encroachment a fill for road construction, residential development, landfilling or other purposes? What date was the encroachment first observ What is its areal extent? To what degree did the encroachment alter the wetland? How does the encroachment evolve? Did the encroachment come in phases or as a one-time occurrence? Is the encroachment composed of fill f an outside source or simply overturned or relocated wetland soil?



IGURE 3 NOVEMBER 10, 1938 APPROX. SCALE 1:6,100

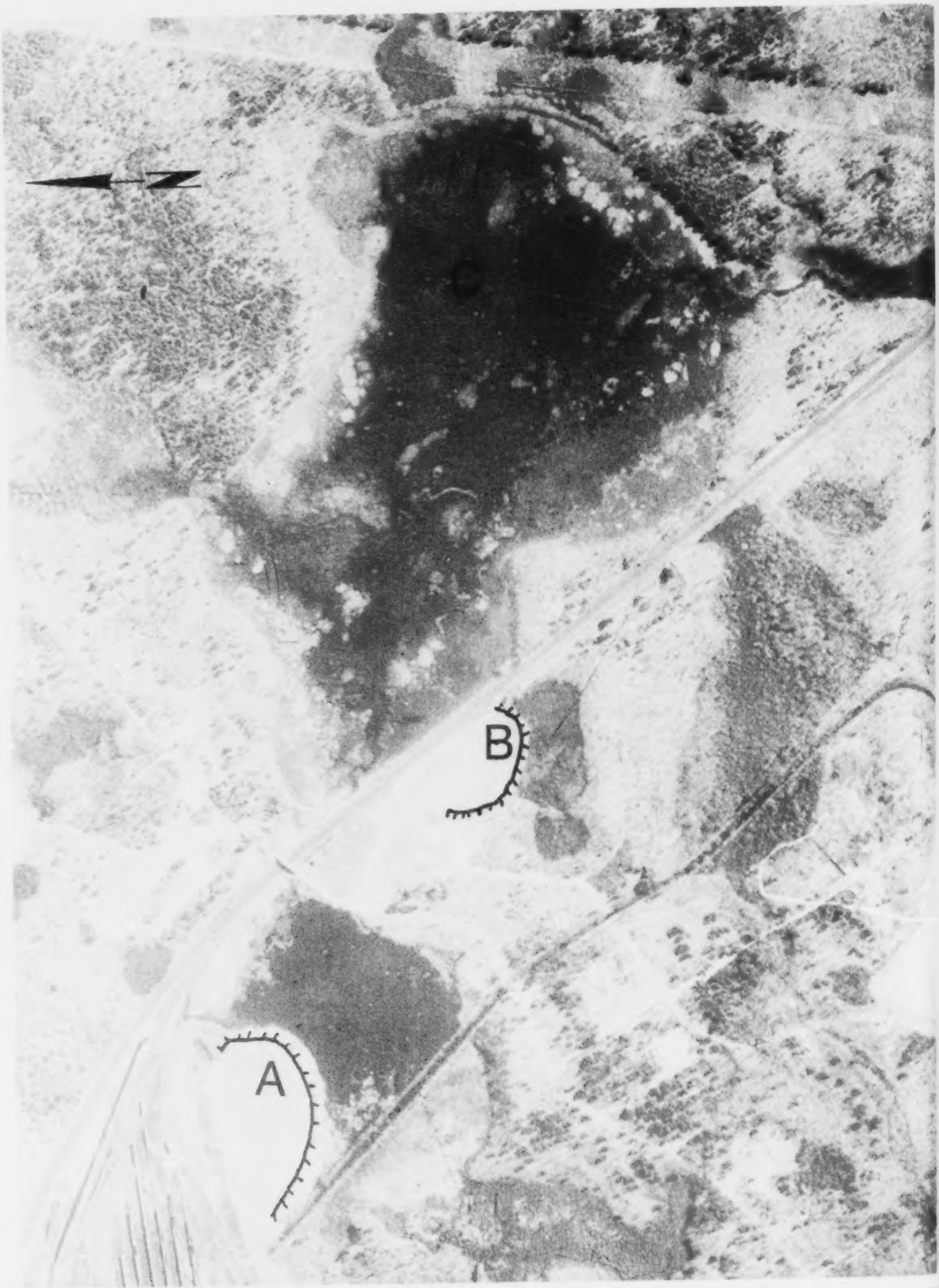


FIGURE 4 MAY 5, 1961 APPROX. SCALE 1:6,5

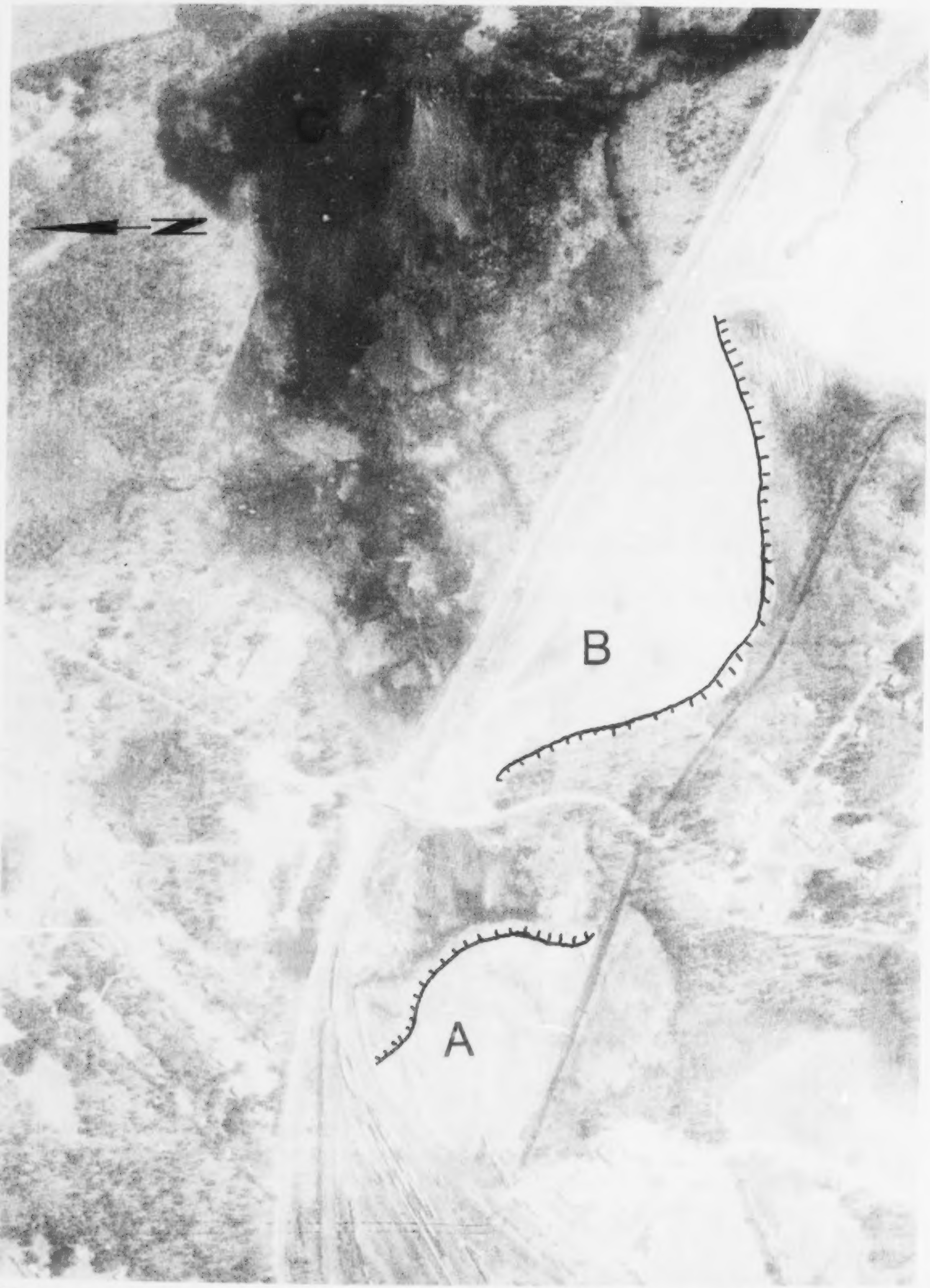


FIGURE 5 MAY 7, 1981 APPROX. SCALE 1:6,500

Comparing Figures 4 and 5, note the encroaching fill areas at A and B. Evidently these wetlands were filled in phases over a period of many years. By 1981 (Figure 5), fill area A has filled approximately 50% of the original wetland area bounded by the canal and railroad. The fill area at B has completely filled the emergent wetland area seen here in 1938. Further study of the fill area at B indicates that it is an industrial landfill which could potentially have a serious impact on ground and surface water quality in the area.

Post-Violation Analysis

Once an encroachment event is complete, or a cease and desist order has been given, several issues continue to need addressing. From the historical information available (back to pre-violation), photointerpretation can sometimes demonstrate which site alterations are covered by Section 404 and which are not. What are the post-violation site conditions? How much of the site area was altered? What portion of the site remains a wetland today? Has the altered portion of a site become upland or some type of modified wetland? Was any further encroachment activity visible after the issuing of a cease and desist order? If so, where and how much? What is the value of the wetland as compared to pre-violation conditions? The following section will illustrate how historical aerial photography can help answer this latter question.

Historical Comparison of a Representative Wetland

The concept of finding a historically similar but unaltered representative of the subject wetland has several potentially useful applications. Through analysis of historical aerial photography it may be possible to find a nearby example of a wetland whose aerial photographic signature is similar to the wetland that is the subject of the 404 action. The ideal situation involves finding a wetland that shows aerial photo signatures identical to the subject wetland on a number of different coverages dated prior to the wetland alteration. Finding such a wetland allows the interpreter to delineate and classify it as seen on both historical and recent aerial photography and then field-verify the findings. This lends credibility to the historical interpretation by showing that the interpreter has correctly classified and delineated similar yet unaltered wetlands that can in fact be verified in the field.

Carrying this comparison further, airphoto identification of similar wetlands can help support onsite efforts to determine the nature and loss of wetland values where there is little or no information on values before alteration. By using Wetland Evaluation Technique (WET) or Habitat Evaluation Procedure (HEP) on similar, unaltered wetlands chosen from historical aerial photography, a wetland scientist can determine the relative habitat value that has been lost or changed due to the wetland alteration. Similar evaluations could be performed on other important wetland functions that have been lost, such as floodwater rentention ability. For illustrative purposes only, assume that the open water wetland areas at A and C (Figure 3) are similar in an important wetland value (floodwater retention). By 1981 (Figure 5) the floodwater retention ability at A has obviously been greatly diminished by filling approximately 50% of the open water area.

These methods can be used to demonstrate the change in overall value of a wetland brought on by the encroachment activity, a significant contribution to settlement and mitigation processes that may follow the enforcement action.

Historical Orthophotographs for a Higher Level of Accuracy

Accuracy of measurements taken from aerial photography is always an important issue. This becomes particularly true when measurements are used as a basis for making important decisions as to the amount of area involved in restoration or removal actions, the size of a mitigation site, or during legal disputes. When accuracy above and beyond that available through delineation and measurement of standard aerial mapping camera photography is required, the EPA has access to photogrammetric technology used to rectify historical aerial photography. Distortion-free aerial photographs called orthophotos can be made from historical aerial photography with proper control, attainable through researching available maps and historical aerial camera calibration records. Once the orthophotos are produced (generally in negative film transparency format), they can be used to make photographic enlargements of a suitable scale. Photointerpretation is performed from stereo analysis of the aerial photography used to make the orthophotos. All delineations can then be transferred into orthophoto format. This method provides a geometrically correct and accurate representation of line work, boundaries and polygon shape and size. The geometrically corrected polygons are then digitized for areal measurement.

Reporting the Findings

Methods of reporting the findings of aerial photo analysis for enforcement actions frequently are based on visual presentation using photo enlargements or poster boards with bold annotations, thematic maps, tabular statistics or area measurements, accompanied by written documentation. Photo enlargements, annotated with wetland categories and cultural features can be prepared, mounted for courtroom presentations or unmounted, with or without text. One photograph with multiple overlays depicting the chronological onsite changes may be useful. Where possible, multiple years of photo information are reduced or enlarged to one common scale for easier, direct comparison. Thematic maps can be produced from digitized photographic information and published at large scales unattainable from photo enlargements. Written documentation, if requested, can accompany any of the previously described products. Included in a written report are full documentation of sources and authenticity of the aerial photography utilized, complete methodology, analysis and findings.

In addition to the enforcement support products described above, EPA's photointerpretation expertise is further utilized through the use of depositions and expert witness testimony when needed.

SUMMARY

In conclusion, the EPA's remote sensing laboratories have successfully employed historical aerial photo analysis in support of interagency enforcement of Section 404 of the Clean Water Act. Historical aerial photography can yield valuable information on site conditions before, during and after a Section 404 violation, and its proper use can contribute to violation discovery, enforcement, settlement, mitigation and monitoring mitigation success. The use of remote sensing will continue to provide valuable support for carrying out EPA's and COE's regulatory responsibilities.

ACKNOWLEDGEMENTS

I wish to thank Douglas Norton for his technical review and input to this paper. I wish also to thank Mary Haller for her editorial assistance, and those members of the staff who assisted me in word processing and photo reproduction for this paper.

REFERENCES

Clean Water Act Section 404, 33 U.S.C. Section 1344, ELR Stat. 42142.

Cowardin, L.M., V. Carter, F.C. Golet and E.T. La Roe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C. FWS/OBS-79/31.

U.S. Department of the Interior, Fish and Wildlife Service. 1986. Photo-interpretation Conventions for the National Wetlands Inventory (unpublished manuscript).

NOTICE

Although the research described in this paper has been funded wholly or in part by the United States Environmental Protection Agency through Contract Numbers 68-03-3161 and 68-03-3532 with The Bionetics Corporation, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

USE OF SPOT HRV DATA IN A CORPS DREDGING OPERATION IN LAKE ERIE

Carolyn J. Merry, Harlan L. McKim and Nancy LaPotin
U.S. Army Cold Regions Research and Engineering Laboratory
72 Lyme Road, Hanover, New Hampshire 03755-1290

John R. Adams
U.S. Army Engineer District, Buffalo
1776 Niagara Street, Buffalo, New York 14207-3199

ABSTRACT

The Corps of Engineers coordinated a water quality sampling program with a dredged material disposal operation and a concurrent SPOT overpass on 4 June 1986. The SPOT HRV 20-m multispectral data were classified into five water categories using a maximum likelihood classifier. A post-classification filter was used to smooth the water classification. Due to the limited amount of ground truth data, simple empirical models are presented to illustrate the association between turbidity and spectral class.

INTRODUCTION

The Corps of Engineers has a wide variety of water-related mission responsibilities, but one of the most important is navigation. There are 25,000 miles of navigable inland waterways in the United States. The barge traffic on these waterways transports millions of dollars worth of commercial goods annually. The Corps is responsible for keeping these waterways open. In addition, the Corps must keep navigation channels open in nearshore and estuarine environments by dredging these channels and maintaining them, in many cases at a minimum channel depth of 35 to 40 ft.

As a result of these dredging operations, millions of tons of material must be disposed of on land, in nearshore environments, or in the ocean. The dredged material from many locations can be used beneficially for beach nourishment projects and in developing waterfowl and fishery habitats. When the dredged material contains pollutants that could be harmful to human and aquatic life, other techniques, such as containment facilities, must be used when disposing of it.

In areas where the impact of unconfined disposal of dredged material must be monitored, the cost of site selection and subsequent water quality monitoring can become very high. It is important in these instances to select representative water quality sampling locations, but it is equally important to minimize the number of water-quality samples required.

With this in mind, a study was done to: 1) review the application of existing remote-sensing techniques for providing data in the Corps' dredging program, 2) define promising new remote sensing techniques for monitoring and managing dredged disposal sites, and 3) recommend which remote sensing techniques should be used now and which should be developed for the future (McKim et al. 1985). It was found that additional research is required to study the use of multispectral scanners for bathymetric mapping of large coastal areas, for mapping sediment transport in shallow waters, for mapping concentration of suspended organic inorganic matter, and for detecting vegetative stress and soil properti (McKim et al. 1985). Along with acquiring multispectral data, ground truth needs to be taken to verify the interpretation of the data.

The spatial resolution and time frequency of data acquisition are important when evaluating remote-sensing techniques for use in the dred ing program. The French Système Probatoire d'Observation de la Terre (SPOT) satellite system is the first operational system that will allow data acquisition and distribution in a short time frame (less than 48 hrs). Initially, the SPOT high resolution and pointable system was evaluated as a means of collecting water-quality data that would augment an it was hoped, reduce the conventional data collection activities of the Corps and the state of Maryland at the Hart-Miller Island disposal area (Band et al. 1984). The research begun at Hart-Miller Island has been continued for the dredging operation in the Toledo Harbor, Ohio, area. This paper reports on the study completed for Toledo Harbor.

DESCRIPTION OF THE SPOT SATELLITE SYSTEM

The French SPOT satellite, launched on 21 February 1986, is in a sun-synchronous, near-polar orbit. For any given region, the satellite images the Earth at the same local time on consecutive passes. In its nominal orbit at 832 km altitude, the SPOT satellite crosses the Equato during its descending node at about 1030 am. The satellite's motion is also synchronized with the daily rotation of the Earth so that the pattern of successive ground tracks is repeated at 26-day intervals.

The sensor package consists of two High Resolution Visible (HRV) sensors. The HRV is a "push-broom" scanner, which means it images a complete line of the ground scene in the cross-track direction in one "look" without any mechanical scanning. The instrument is also pointab and can image an area on the ground ±27° from nadir. When the satelli is pointed straight down at nadir, the HRV's image adjacent 60-km groun areas. There is a 3-km overlap in the center for a total image width o 117 km.

The satellite can point off to either side of nadir at 0.6° incre ments and can thus image any area within a 950-km swath centered over t orbital path. This allows for stereo acquisition of imagery and for mo revisit opportunities over an area of interest than is possible with th Landsat series. At the latitude of 42°N for Hanover, New Hampshire, sensor could image an area 11 times during a 26-day orbital cycle. A maximum of six stereo-pairs can also be obtained during the 26-day cycl

The data are of high radiometric quality with 8-bit resolution fo 256 radiometric levels. There are two modes of instrument operation:

multispectral and panchromatic. The 20-m multispectral mode covers three spectral regions--two in the visible (0.50-0.59 μm, 0.61-0.68 μm) and one in the near infrared (0.79-0.89 μm). The 10-m panchromatic mode covers a wide band ranging from 0.51 to 0.73 μm. Additional details on the SPOT satellite system can be found in Begni (1982), Begni et al. (1984), Chevrel et al. (1981), and CNES (1982).

In this paper we address the possibility of using the off-nadir viewing capability with 20-m multispectral data for mapping relative ranges of suspended sediment concentration associated with a Corps dredged material disposal operation.

GROUND TRUTH DATA ACQUISITION

The Buffalo District, Corps of Engineers, conducted a monitoring program during the summer of 1986 to study the effects of open-lake disposal operations on the water quality of Lake Erie. The dredged material disposal area is located northeast of Toledo, Ohio, and is within the rectangle located southeast of the navigation channel (Fig. 1).

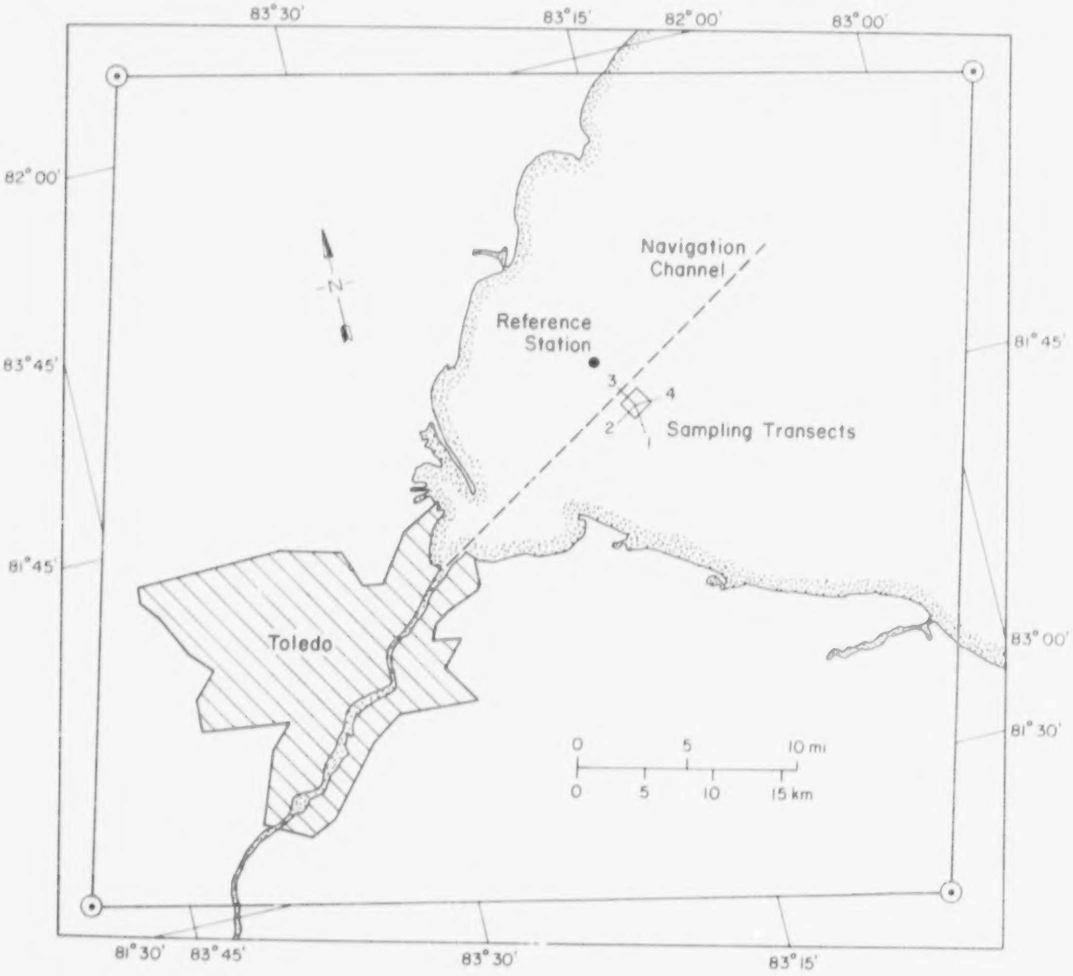

83°30'
83°15'
82°00'
83°00'
82°00'
83°45'
81°45'
81°45'
83°00'
81°30'
81°30'
83°45'
83°30'
83°15'
N
Navigation Channel
Reference Station
3
4
2
1
Sampling Transects
Toledo
0
5
10 mi
0
5
10
15 km

FIGURE 1. Site location map of the study area.

TABLE 1. MEASUREMENTS FROM THE WATER QUALITY STATIONS LOCATED NEAR THE DREDGED MATERIAL DISPOSAL SITE AT THE TIME OF THE SPOT OVERPASS.

Location no.	Suspended sediment (mg/L)*	Turbidity (NTU)*	Secchi depth (ft)
1	2.0	19.0	2.0
2	2.0	7.3	2.5
3	2.0	6.8	2.5
4	7.0	26.0	2.0
5	5.0	18.0	2.5
6	<1.0	7.9	2.5
7	<1.0	8.3	3.0
8	8.0	23.0	2.0
9	3.0	20.0	2.5
10	2.0	20.0	2.5
11	1.0	6.1	3.0
12	1.0	5.7	3.0
13	6.0	7.5	3.5

* The measurement accuracy of the suspended load concentration for the sampling procedure used by the District is ±2 mg/L.

† NTU = Nephelometric Turbidity Units.

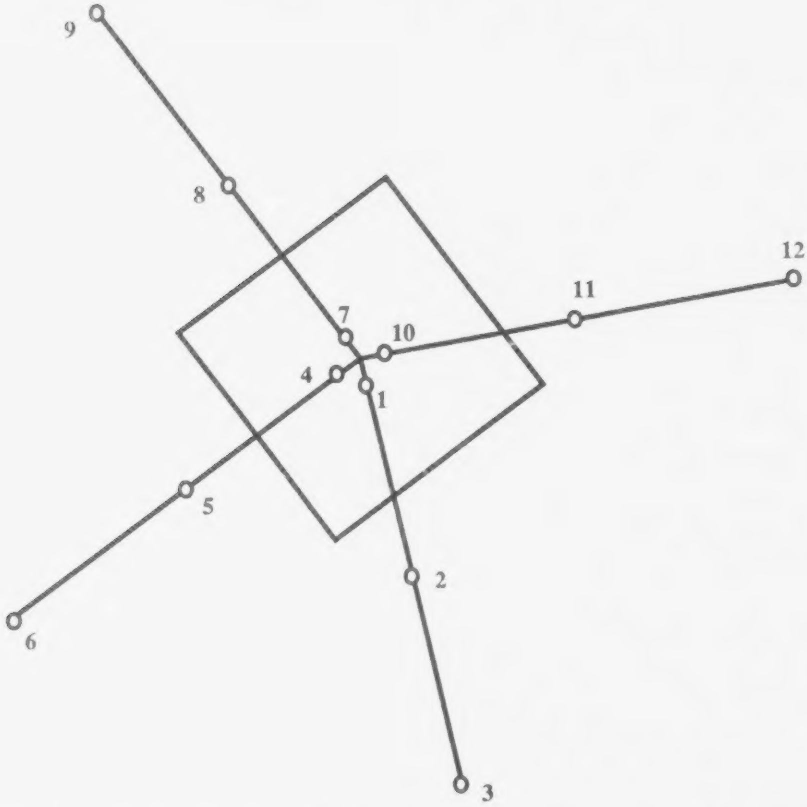


FIGURE 2. Location map of the water quality sampling stations.

The dredged material disposal operation occurred over a period of 14 weeks, starting on 7 April and ending on 8 June 1986. In situ measurements of water quality were performed twice before the dredging operation began on 7 April. Water quality measurements were then made every week until 18 June 1986, including two measurement sets after dredging ceased on 8 June 1986.

A programming request was made of SPOT IMAGE Corporation to obtain SPOT HRV data over the Toledo area during the Corps dredging operation. The District's water quality sampling program was readjusted to coordinate with a dredged disposal operation and a SPOT overpass on 4 June 1986. As a result, a completely cloud- free SPOT image was acquired successfully on 4 June at 1242 hrs (DST).

The water quality data taken on June 4 are shown in Table 1, with the location of the water quality sampling stations shown in Figure 2. Seventy percent of the dredged material disposed of during the 4 June operation was clay.

ANALYSIS OF THE SPOT HRV DATA

1. Matching the image to the map

The SPOT HRV data set was analyzed on a Dipix ARIES-II image-processing system. The HRV image was registered to a NOAA map sheet (scale 1:40,000) using an Altek digitizing table and Gentian controller interfaced to the image-processing system. The navigation channel and the location of the water quality sampling stations were located, digitized, and stored as overlay theme files on the SPOT image.

Interpretive analysis of the spectral reflectance data for the entire SPOT scene indicated that there were five to seven different water types in the area of interest. Using this infor-mation as a guideline, a 723- by 670-pixel subarea (approximately 8.5 miles on a side) that contained the dredged material disposal area was selected from the HRV image for analysis.

2. Unsupervised classification of data

An unsupervised maximum likelihood classification was performed on the subarea. The classifier delineates "equiprobabil-ity contours," which can be represented as ellipsoids. A normal probability density function is calculated for each of the ellipsoids, which are also characterized by a mean vector and a covariance matrix. The probability density function is used to classify an unknown pixel by computing the probability of a pixel belonging to each of the categories. After the probabilities are evaluated, the pixel is assigned to the most likely class.

The unsupervised classification procedure of the ARIES-II software generates *n*-dimensional histograms, with the *n* dimensions in this case representing the three SPOT spectral bands, and searches for maximum values within each histogram. There were 17 maximum histogram peaks generated for the three-band data. The 17 maxima were then merged into five multiple parallelepiped classes to create Gaussian multispectral signatures. A maximum likelihood classification was performed on the data set using these five spectral signatures.

There were many unclassified pixels in the initial water classification. Therefore, post-classification filtering was performed on the classification map. The filtering algorithm is based on the minimum a of a homogeneous theme, 7 pixels in this case (Dipix Systems Limited 1986). Results from the smoothing algorithm showed that the water cla sification was not affected significantly. The differences between th "before" and "after" maps of the areal distribution of each class were less than 2%.

3. Matching the image data to the water quality data

To correlate the water quality data at the 13 stations with the spectral class information, the overlay of the water quality sampling locations was superimposed on the water classification map (Fig. 3). Spectral class 1 was the least reflective water and spectral class 5 contained the most reflective water. The basis for this interpretatio is that in pure water the attenuation of light is dominated by the absorption of water below wavelengths of 0.3 mm and above 0.7 mm (Morel 1974). The presence of particulate and dissolved material in the wate

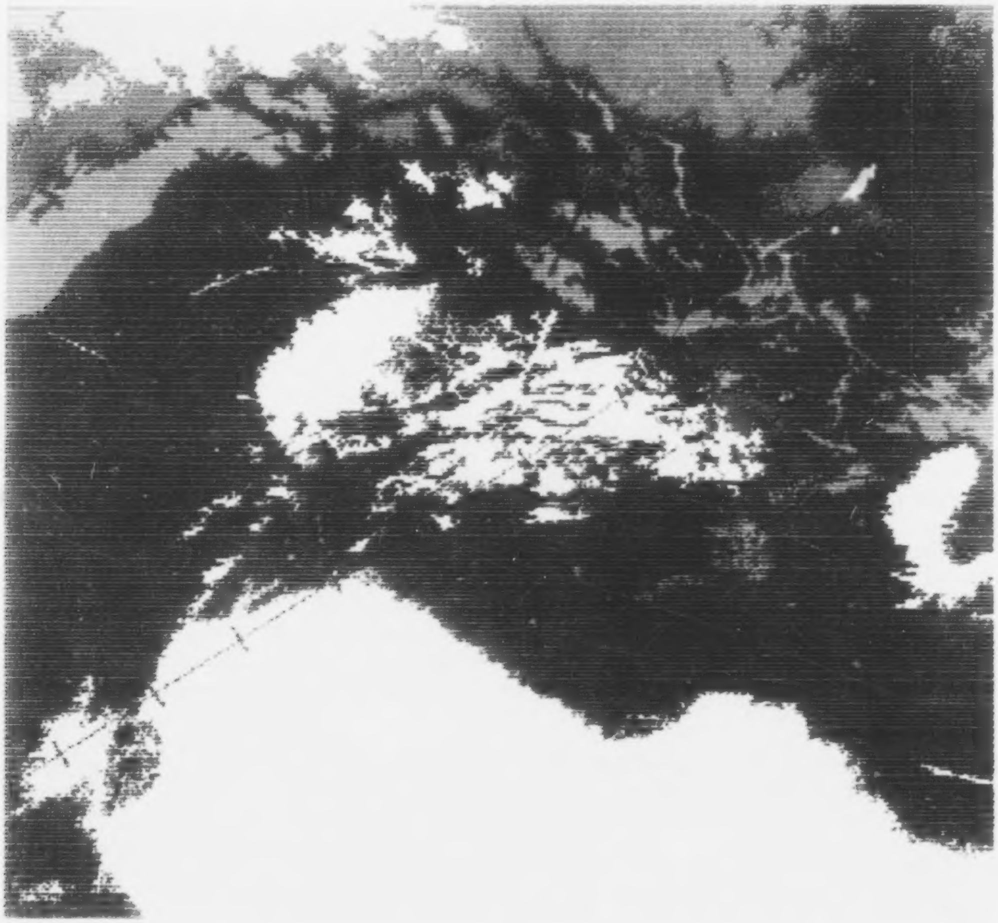


FIGURE 3. Water sampling transects and navigation channel overlaid on the water classification map.

affects the penetration of light in water and the intensity and color of the light scattered back in the direction of the remote sensor (Philpot and Klemas 1979). Since spectral class 1 had the lowest values for all three bands and spectral class 5 the highest, spectral class 5 contained the greatest suspended sediment load.

The water quality data from the 13 locations were analyzed next. Sampling point 13 represents the District's reference sampling location and is considered an outlier.* The strongest correlation beween the water quality data shown in Table 1 and the spectral classes was found with the turbidity (measured in NTUs), which is a measure of light scattering. However, a quantitative measure of suspended load is normally expressed in mass per unit volume or concentration (mg/L). To obtain the relationship between the concentration and the spectral class, two models were developed. The first model related the turbidity level (in NTUs) to the suspended sediment concentration (in mg/L) and the second model related the turbidity (in NTUs) to the spectral classification index (from class 1 to 5).

An exponential model correlating the suspended sediment with the turbidity is presented in Equation (1).

$$y = (0.511)\ (10^{0.042x}) \qquad (1)$$

where y = suspended sediment concentration (mg/L)
x = turbidity (NTU).

About 64% of the variance in suspended sediment concentration is explained by using the turbidity value as an indicator (Fig. 4). The standard error of the model is 0.01 mg/L.*

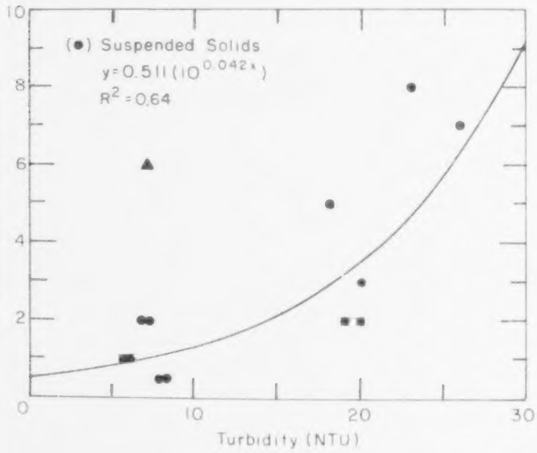


FIGURE 4. Exponential model relating suspended sediment concentration (mg/L) to turbidity (NTU).

---

* The suspended sediment concentration for point 13 is high in comparison to the other data (6.0 mg/L), the turbudity value is low (7.5 NTU), but the Secchi disk depth is high (measuring 3.5 ft), which is inconsistent with the other 12 data values (see Fig. 7 and Table 1). In addition, the spectral values for point 13 were examined in each band to check for inconsistencies and were found to be representative for spectral class 2. This implies a probable measurement error with point 13, perhaps resulting from the relatively low concentrations of suspended sediment (ranging from < 1.0-8.0 mg/L).

† The measurement accuracy of the suspended load concentration for the sampling procedure used by the District is ± 2 mg/L.

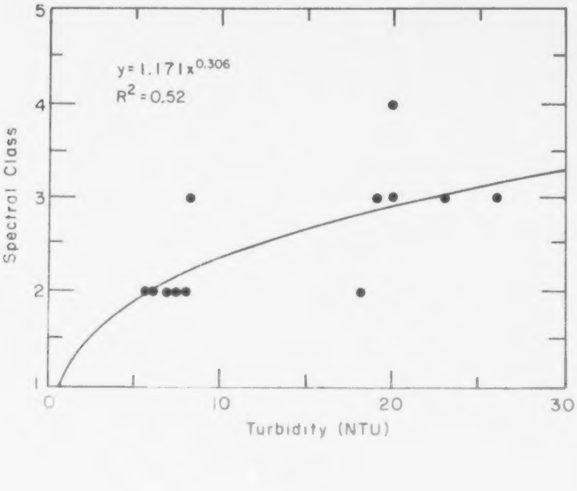


FIGURE 5. Logarithmic model relat
spectral classification to turbud
level.

The model developed relating the spectral class to the turbidity level is presented in Equation (2). The relationship was logarithmic o the form:

$$y = (1.171)\ (x^{0.306}) \qquad (2)$$

where y = spectral class (from 1 to 5)
x = turbidity (NTU).

The coefficient of determination for the model is 0.52, suggesting that 52% of the variation in spectral class definition is explained by using the turbidity value as an indicator (Fig. 5). The model illustrates th non-linear association between turbidity and spectral class, however, i should be used solely as an illustrative model due to the small sample size (12).

SUMMARY AND CONCLUSIONS

The results from the study indicate that the 20-m multispectral data from the SPOT satellite is useful for differentiating between relative suspended sediment levels at dredged disposal areas. Around the immediate dredged disposal area, very little variation was seen in the water quality sampling data. The sparsely sampled ground truth data an the 2 mg/L measurement accuracy did not warrant a complete statistical analysis of the digital image data. The first model showed a nonlinear association between suspended sediment concentration and turbidity. Th highest nonparametric correlation (0.807) for spectral class separation was with the turbidity value (in NTUs) for low levels of suspended sediment.

Future efforts should include measurements at both surface and no surface points. In addition, algorithms need to be developed to relate surface measurements to subsurface concentration profiles and spatially distribute this information across the test area. Provided that an adequate sample size is obtained, equations of the form (1) and (2) might helpful for correlating SPOT image data to water-quality sampling and other ground truth measures.

Because of the small amount of field data available from the study, another test will be performed. Near real-time remotely sensed information, such as the NOAA Advanced Very High Resolution Radiometer (AVHRR) imagery, will be used to select areas of Lake Erie for positioning the water quality sampling transects. Additional point data will be collected over a wider range of turbidity or suspended sediment concentration data. These measurements will be made over the entire water column as determined by the secchi depth measurement. This will allow comparison with the data collected in June 1986.

ACKNOWLEDGMENTS

The work was sponsored under the Corps of Engineers Civil Works Remote Sensing Research Program, CWIS 31746, Evaluation of SPOT and Landsat-4 Satellite Data Products, and reimbursable orders from the Buffalo District, Corps of Engineers and the Water Resources Support Center, Dredging Division (WRSC-D). Appreciation is extended to Eleanore Meredith (SPOT IMAGE Corporation) for her help in coordinating with SPOT IMAGE to acquire the satellite image during our water-quality sampling program; to Charles Hummer (WRSC-D) for his support of our research with SPOT HRV data for application to the Corps Dredging Program; to Perry LaPotin for helpful technical discussions; and to Richard Birnie (Dartmouth College), Stephen Yaksich (Buffalo District, Corps of Engineers) and Andrew J. Bruzewicz (Rock Island District, Corps of Engineers) for technical review of this report.

LITERATURE CITED

BAND, L.E.; MCKIM, H.L.; MERRY, C.J., "The Potential Use of SPOT HRV Imagery for Analysis of Coastal Sediment Plumes," SPOT Simulation Applications Handbook, *Proceedings of the 1984 SPOT Symposium, Scottsdale, Arizona, 20-23 May, 1984*, pp. 99-204.

BEGNI, G.A., "Selection of the Optimum Spectral Bands for the SPOT Satellite," *Photogrammetric Engineering and Remote Sensing*, vol. 48, no. 10, 1982, pp. 1613-1620.

BEGNI, G.; LEGER, D.; DINGUIRARD, M., "An In-Flight Refocusing Method for the SPOT HRV Cameras," *Photogrammetric Engineering and Remote Sensing*, vol. 50, no. 12, 1984, pp. 1697-1705.

CHEVREL, M.; COURTOIS, M.; WEILL, G., "The SPOT Satellite Remote Sensing Mission", *Photogrammetric Engineering and Remote Sensing*, vol. 47, no. 8, 1981, pp. 1163-1171.

CNES, "SPOT Satellite-Based Remote Sensing System, CNES: Paris, France. 1982.

DIPIX SYSTEMS LIMITED, ARIES System User's Manual, 1986.

LILLESAND, T.M.; KIEFER, R.W., *Remote Sensing and Image Interpretation*, John Wiley & Sons, Inc.: New York, New York, 1979.

MCKIM, H.L.; KLEMAS, V.; GATTO, L.W.; MERRY, C.J., "Potential of Remote Sensing in the Corps of Engineers Dredging Program," CRREL Special Report 85-20, 47 p, 1985.

MOREL, A., "Optical Properties of Pure Water and Pure Sea Water", *Optica* *Aspects of Oceanography*, Jerlov and Nielsen (eds.), Academic Press: New York, 1974.

PHILPOT, W; KLEMAS, V., "The Use of Satellites in Environmental Monitoring of Coastal Waters," Final Report, CRS-1-80, NASA Langley Research Center: Hampton, Virginia, 1979.

LOCATING SUSPENDED SEDIMENT SOURCES AND SINKS WITH LARGE LANDSAT DATA SETS

Michael S. Fedosh

U.S. Army Corps of Engineers
26 Forest Plaza
New York, NY 10278

ABSTRACT

Suspended sediment is an inherent problem in the waterways of the United States. Resolving this problem falls upon the Army Corps of Engineers which is responsible for navigation, flood control and water quality. Locating suspended sediment sources may assist in the reduction of sediment loads into rivers and estuaries. Located suspended sediment sinks means locating potential pollutant sinks and provides assistance in planning dredging schedules. If suspended sediment pathways are known, then reducing sediment input may reduce the frequency of maintenance dredging and improve general water quality. In Corps districts where water disposal of dredged material is necessary there are concerns whether the disposal material will stay in place or be resuspended into the water column. Knowing areas and causes of resuspended sediment in the water column can address those concerns.

Landsat studies have long been using suspended sediment as a circulation and sediment pathway tracer in rivers, estuaries and coastal waters. A problem occurs in these studies if a limited number of Landsat scenes relative to the complete cloud-free data set are used. Suspended sediment patterns detected in these few scenes may not be representative of normal conditions and may have been resuspended by conditions unique for an individual image. The extent of resuspension depends on the combination of fluvial volumes, wind direction and speeds, seasons and tidal phase. Environmental effects unique to a few scenes can be minimized when using the complete set of cloud-free Landsat images for a particular scene from its initiation in 1972.

An optical density analysis of Landsat film transparencies would show spatial variations of suspended sediment concentrations. Film density, indicative of suspended sediment concentrations, is measured along

selected transects. After normalization, the optical density values of each sampling station are averaged for the entire Landsat cloud-free data set. The average optical density profile is subtracted from the optical density profiles of each Landsat image to produce a residual profile which inversely shows above and below average suspended sediment levels. The residual profiles of Landsat images with a similar wind direction and speed, tidal phase, fluvial discharge, or season can be averaged to produce a profile showing suspended sediment levels for that particular condition. Areas of above average turbidity suggest resuspension due to the condition which is isolated through the averaging process.

The Virginian portion of Chesapeake Bay was used to test the averaging of residual optical density profiles. Fifty-nine images from 1972 to 1981 were sufficient for separating tidal and meteorological influences and showing an association of above average turbidity with depth, maximum velocity tidal currents, higher wind speeds and spring tide conditions.

In the future, averaging of Landsat data can be applied to computer compatible tapes where pixel averaging can create qualitative "scenes". Suspended sediment concentrations can be correlated with reflected radiance values to provide quantitative suspended sediment volumes related to specific tidal and meteorological conditions isolated through averaging the historical Landsat data.

INTERPRETATION OF AERIAL IMAGERY
TO DETERMINE
PLACES, TIMES AND EXTENTS OF WETLAND FILLS

BY
BILL CLEMENT
CARTOGRAPHY AND REMOTE SENSING SECTION

AND
FRANK FLYNN
REGULATORY BRANCH

PORTLAND DISTRICT
ARMY CORPS OF ENGINEERS

ABSTRACT

The US Army Corps of Engineers has regulatory authority over activities occuring in the Nations waterways. Remote sensing has recently been introduced in Portland District as a tool in enforcing Corps regulatory authority. Remote Sensing personnel have successfully used the following techniques: (1) Comparisons of aerial imagery from different time periods to identify the locations of illegal fills; (2) Identification of the original boundaries of wetland areas that have been covered by illegal fills; and (3) Determinations of the times and acreages of illegal fill events. This type of analysis provides evidence of a quantitative, visual nature that has resulted in expeditious resolution of enforcement actions.

INTRODUCTION

Use of aerial photographic interpretation techniques allows Corps regulatory investigators to quickly determine the extent of ongoing violations of section 404 of the Clean Water Act. Additionally, these techniques are of assistance in relating past fill activities to the time frame under which the Corps has assumed regulatory authority over different waters of the United States.

IDENTIFICATION OF VIOLATIONS: KLAMATH FALLS, OREGON

Upon transfer of responsibility for regulation of fill placement in waters of the Klamath basin, Oregon, from San Francisco District to Portland District, the Cartography and Remote Sensing Section was asked to do a baseline survey of the area. 1:12,000 scale aerial photography taken in 1980 was obtained from the San Francisco District, and aerial photography at the same scale was flown during 1985. These images were compared on a zoom transfer scope, and several suspected violations were identified. A ground truth investigation by personnel from Regulatory Branch, Cartography and Remote Sensing Section, and the Oregon Division of State Lands confirmed the existence of four major violations.

MAPPING THE EXTENT OF CURRENT DAMAGE TO A WETLAND

The Jackson Frazier wetland, Corvallis, Oregon, has been classified as a habitat unique and irreplaceable on a national basis.

The wetland includes populations of several species considered to be rare and critically endangered in Oregon. The property owner brushed and disced parts of the property with the stated intention of eliminating one of the endangered plant species (Lomatium Bradshawii), preparing the ground for conversion to agriculture, and later urban development. Other areas of the wetland were cleared, and ditches dug in an attempt to drain the wetland area. Cartography and Remote Sensing Section personnel were called in to assist in a wetland assessment, and to determine the extent of damage to the wetland. Aerial photography from several dates was used to delineate wetland boundaries, vegetation classifications within the wetland, areal extent of the disced area, length and location of drainage ditches, and volumes of sidecast material. A restoration order was subsequently issued. The state is pursuing civil and criminal penalties against the property owner, and the EPA is attempting to require additional restoration of the property.

MAPPING THE EXTENT OF PAST WETLAND FILLS

Portland District inspectors addressing fill violations have often limited their investigation to ongoing or relatively recent fill activities. Fills placed in the past on wetlands, and now covered with vegetation or currently being used by the property owner were considered to be extant upland, not upland created by illegal fill activity. In many instances, particularly in enforcement actions involving commercial developers or industrial property, the fills have occurred slowly over a period of several years. Consequently, past fills placed in violation were overlooked while the investigation focused only on obvious areas of fresh fill.

Drilling or ditching to expose buried environments, specifically the buried soil types, vegetation and hydrologic indicators, is too costly and time consuming to be used routinely. Records from other governmental entities, for example County floodplain fill permits, tend to lack specificity regarding the environment being filled. Normally there is no distinction made between non-wetland floodplain and floodplain wetlands. Consequently, the Corps often lacks sufficient documentation to assert its regulatory authority.

A permit application was made to fill a small (0.8 ac) wetland area in Beaverton, Oregon. The Cartography and Remote Sensing Section was asked to verify the possibility that an adjacent 0.5 acre area had been previously filled without a permit. Large scale aerial photographs from 1970 to the present were procured and interpreted for wetland indicators using stereoscopy for vertical changes. Aerial photointerpretations were recorded on mylar at a common scale of 1"=200' for easy comparison. A ground visit was made to the area of interest to correlate actual ground conditions with current aerial imagery. Contacts with Corps Regulatory Branch personnel were made to verify species characteristics at different seasons. The 13 April 1971 imagery showed bunches of detached dead grasses that were distributed on a hillside along a line of equal elevation, thus indicating seasonal inundation. The 9 May 1977 imagery indicated a five acre area of light toned vegetation later ascertained to be senescent reed canary grass (a local wetland indicator species) relict from the 1976 growing season. Early 1977 imagery showed areas having an appearance suggesting recent vegetation regeneration,and detailed analysis of the appearance of this imagery compared with ground truth data of vegetation regeneration rates from nearby sites indicated that the fill had been placed in late 1978 or early 1979, after the Corps assumed regulatory jurisdiction over this area on 1 July 1977. Later imagery showed areas with obvious spoil piles, indicating fill in progress. Thus the existence of a past wetlands area was discovered, the areal extent of the original wetland was quantified, and an ongoing wetland fill violation was identified. A small wetland area fill application (the existing 0.8 acres) would probably have been approved without mitigation, but discovery of this larger five acre wetland area fill violation will probably result in denial of the permit application with a requirement for full restoration.

A complaint of an in progress illegal fill near Suttle Road, Portland, Or. was received by Regulatory Branch. Upon initial site inspection the investigator determined that the extent of the violation might be larger than orginally anticipated. Again historic aerial photography was obtained and interpreted to ascertain the original wetland boundary. Boundary indicators were found on the imagery and identical indicators were located at a nearby existing wetland-upland boundary. In the process of this interpretation, it was found that three adjacent property owners were also in violation. In one stereo image a dump truck was observed moving away from a spoil pile, its dump bed lower in one image than the other, with a bulldozer parked nearby. Corps counsel and the land owners attorneys are still negotiating about what would constitute a reasonable resolution of this violation. The situation is further complicated because some of the property owners also appear to be in violation of water pollution and hazardous waste disposal regulations.

Cartography and Remote Sensing Section personnel have also been asked to employ the interpretation of aerial photographs to map rough maximum extents of wetlands. These maps help Regulatory Branch personnel decide which property owners in an area should be sent cease and desist orders prior to wetland investigations.

CONCLUSION

Aerial photography has often been utilized by regulatory personnel for reconnaisance efforts and as a base map for field work. In addition, the analysis of aerial photography by an experienced photo interpreter has proven an invaluable tool to Regulatory Branch personnel attempting to find out the true story at a suspected wetland fill violation.

THE USE OF SPATIAL DATA BASES AND DATA BASE MANAGEMENT SYSTEMS TO IMPROVE PLANNING FOR AND CONTROL OF THE DISPOSAL OF DREDGED MATERIAL

Cynthia A. Abrahamson

and

Andrew J. Bruzewicz

U.S. Army Corps of Engineers, Rock Island District
Clock Tower Building
P.O. Box 2004
Rock Island, IL

and

Mark Johnson

U.S. Army Construction Engineering Research Laboratory
P.O. Box 2004, Champaign, IL

ABSTRACT

Significant expenditures are involved in the operations and maintenance budgets of most Corps of Engineers Districts for dredging and the consequent disposal of dredged material. With decreases in the manpower available to manage these activities, increasing costs, and budget constraints necessitating operating as cost effectively as possible, it i critical that the necessary information be readily available in a convenient and easily usable form.

To illustrate the use of spatial data and a data base management system (dbms) in an integrated data management system (idms) context, the Rock Island District (NCR) has used its Geographic Resources Data Analysis Support System (GRASS) software on a digital data base obtained for one the District's most frequently dredged areas, Keithsburg, Illinois, locat 20 miles north of Burlington, Iowa, on the Mississippi River.

A National High Altitude Program (NHAP) color infrared aerial photograph transparency which was digitized with 5- by 5-meter pixels and rectified

was used as the base map. Additionally, the road network, sailing line, dredge cut, and potential and historical disposal sites for dredged materials were digitized. This information is available on a computer compatible tape (CCT) and can be stored on the system's hard disk.

Using the idms capabilities of the system, the locations of dredged material can be related to tabular files which contain information about use of each disposal site: years during which the site was used; quantity of material placed; and, when available, the cost of the dredging event, land ownership, and any pertinent information. Ancillary information to be added at NCR will include the location of river training structures such as wing dams, utility crossing, topography, soils, geology, archaeological sites, fleeting areas, environmentally sensitive areas, levee districts, recreation areas, boat ramps and land ownership.

Use of the system enables immediate analysis of the frequency of dredging, quantities, and cost. Examination of the geophysical display shows all potential disposal sites in the area. Distance to any site can be immediately determined. Effectiveness of training structures can be determined and preliminary estimates of the need for additional structures made. It is possible to easily and rapidly update records for the most recent dredging season. Updates will include notations for sites which have been filled both in the dbms files and through the use of special symbols on the graphics display. As new disposal sites become available, they are easily added, and the system facilitates report generation. In the future, models will be developed to identify potential disposal sites.

SESSION II

APPLICATION OF POLAR-ORBITING NOAA/AVGRR AND TOVS DATA FOR WATER RESOURCES MANAGEMENT OF THE GREAT LAKES

Roger L. Gauthier

and

Karen H. Lee

U.S. Army Corps of Engineers
Detroit, MI

ABSTRACT

The tasks of forecasting and regulating water levels and monitoring ice conditions on the Great Lakes have been adversely influenced by a lack of timely hydrometeorologic observations over the region. Snowpack, ice cover, and surface temperature observations, collected with both spatial and temporal integrity, are key concerns. Near real-time information on snowpack and soil moisture conditions and lake surface temperatures, largely unavailable in the past, are needed for development of new-generation simulation and forecasting water supply models.

The present series of NOAA polar-orbiting operational satellites provide multispectral observations of surface conditions and sounding profiles of the atmosphere. Data collected by the Advanced Very High Resolution Radiometer (AVHRR) has been processed by the Detroit District, U.S. Army Corps of Engineers (USACE) to map snowpack extent and ice cover conditions over the Great Lakes. Information collected by the onboard TIROS Operational Sounder (TOVS), in conjunction with AVHRR observations, has been applied by various researchers to map sea surface temperatures in an operational setting.

The application of NOAA satellite observations to Great Lakes water quantity management and icepack monitoring is actively being investigated. Polar-orbiting satellite observations are being tested, in conjunction with various point (ground) and linear (airborne) observations of hydrometeorologic conditions, in the development of improved operational modeling approaches. Present findings and anticipated future directions are discussed.

DETERMING AREAL FLOOD EXTENT IN SAGINAW COUNTY, MICHIGAN WITH LANDSAT THEMATIC MAPPER DATA

Karen H. Lee

and

Roger L. Gauthier

U.S. Army Corps of Engineers
Detroit, MI

and

Wendy S. Hutchinson

The Ohio State University
Columbus, OH

ABSTRACT

The problem of determining the extent of flooding in a large basin
ideally suited for the use of Landsat Thematic Mapper (TM) data. S
problem occurred as a result of a series of storms which began in
early-September and lasted until early-October 1986. This series o
downpours caused widespread damage across most of central lower Mi
The Saginaw River and its tributaries experienced considerable flo
throughout their basins, exceeding all previous record flood stage
one 48-hour period, precipitation ranged from 8.5 to 13 inches ove
10,000 square mile area. Total precipitation for the month of Sep
1986 was over 17 inches in the city of Saginaw. In Saginaw County
estimated damages to the public, private, and agricultural sectors
approximately $50 million.

The extent of flooding in the Saginaw County portion of the river b
determined by comparing the areal water coverage from two Landsat T
scenes. The first scene was collected on August 24, 1984, during

"within channel" conditions on the Saginaw River. The areal extent of water coverage was determined by using clustering and masking techniques on the Detroit District's image processing system. In addition to the normal extent of water coverage, Level I/II land cover classifications were derived from the TM data for the study area. A second Landsat TM image was obtained from October 7, 1986, shortly after the last major storm event, when the Saginaw River was at or near its peak flood stage. A similar analytical approach was performed on the October 1986 scene to determined the areal water coverage during peak flows. Land cover classifications, derived from the 1984 scene were used to quantify flooded areas, by cover type, for future economic and environmental assessments.

EMERGENCY OPERATION FLOOD AND FLOOD STORAGE FORECAST MAPPING: A SOLUTION BY SATELLITE AND SIMULATION*

Jack Stoll

U.S. Army Corps of Engineers Waterways Experiment Station
Vicksburg, MS

---

*Abstract not available

THE ACQUISITION AND USE OF USGS DIGITAL ELEVATION MODELS

Henry A. Edwardo, Judith A. Tutino and Carlton E. Hackett
U.S. Army Engineer District, Pittsburgh
Pittsburgh, Pennsylvania 15222-4186

ABSTRACT

Digital cartographic products being developed by the U. S. Geological Survey hold great promise for the Corps of Engineers as the available data base grows and we gather the experience and resources to use these efficiently. This paper will describe the experiences of the Pittsburgh District in acquiring and using 1:24,000 scale digital elevation models for five 7.5 - minute quadrangles covering a 67 square mile watershed near Pittsburgh, Pennsylvania. This data was used to develop hydrologic parameters for stormwater runoff modeling to evaluate the technical and economic feasibility of flood warning systems in reducing flood damages and loss of life in the Pine Creek Watershed.

BACKGROUND

At approximately 5:00 PM EDT on Friday, May 30, 1986, heavy thunderstorms in the North Hills area of suburban Pittsburgh caused severe flash flooding in the Pine Creek Watershed. Eight deaths were confirmed and one person is unaccounted for as of the writing of this paper. Property damage to residential and commercial structures was extensive, public roadways were eroded and numerous small private bridges were damaged or destroyed. On June 6, 1986, the President declared that damages resulting from this flash flooding constitued a major disaster in the Commonwealth of Pennsylvania and eight municipalities in the watershed were determined to be eligible for Individual Assistance. On June 9, 1986, the Commonwealth of Pennsylvania, Department of Environmental Resources (DER) requested the Pittsburgh District, Corps of Engineers to perform a reconnaissance level study to determine the technical and economic feasibility of developing an automated flood warning network for the Pine Creek Watershed pursuant to the FY 87 Section 22 Planning Assistance to States Program.

The study was initiated in October 1986 and a decision was made early on to assemble available physiographic and resource data for the Pine Creek Watershed into a computerized geographic information system (GIS). This was guided by the experiences of the Pittsburgh District in similar work over the past decade and the availability of in-house digital image processing hardware and software. The GIS developed for the Pine Creek Watershed consists of a series of computer data files, each containing basic physiographic information such as land cover and ground slope, for 194,127 individual cells covering the entire 67.3 square mile Pine Creek drainage area. These cells represent a rectangular grid oriented to north that divides the study area into 30-meter by 30-meter pieces, or grid cells, which contain information or a code for data found in that piece of the study area. The data which has been encoded in this digital format is summarized in TABLE 1.

TABLE 1
PINE CREEK WATERSHED
GEOGRAPHIC INFORMATION SYSTEM

DATA VARIABLE	DESCRIPTION
Subbasins	Areas of the 11 major tributaries to Pine Creek and the local drainage to Pine Creek above and below North Park Lake Dam.
Hydrologic Soils	Areas representing the four groups of soil types which relate to soil perviousness.
Land Cover	Eight land cover types developed from computerized interpretation of Landsat satelitte multispectral sensor data acquired on June 5, 1985.
Ground Slope and Elevation	Digital topographic data at a scale of 1:24,000 developed by the U.S. Geological Survey for the five 7.5-minute quadrangles covering the Pine Creek Watershed
Municipalities	Areas of the 14 municipalities in the Pine Creek Watershed
Emergency Service Areas	Areas covered by the three emergency dispatch centers in the watershed.
May 1986 Rainfall	Isohyetal zones for the storm of May 30, 1986.

The Hydrologic Engineering Center (HEC) computer program HYDPAR (Hydrologic Parameters) can access such a data base and generate basic input to the HEC-1 rainfall-runoff model. These procedures were developed by the HEC in the mid-1970's in support of the Expanded Flood Plain Information Study effort and are part of a larger set of programs originally known within the Corps as spatial analysis methodology or HEC-SAM. The Pittsburgh

District conducted one of ten nationwide HEC-SAM pilot studies in that time frame for the Upper Sewickley Creek Watershed (Reference 1), which at that time was the fastest growing area of the Commonwealth of Pennsylvania. At present, the parameters that can be generated by the HYDPAR program are those needed for the U.S. Soil Conservation Service (SCS) Curve Number (CN) technique and those needed for watershed modeling using subbasin imperviousness and characteristics of the Snyder unit hydrograph procedure. The data variable essential in these calculations is ground slope. As was true for the Sewickley Creek Study and which remained true for the Pine Creek Study, topography is potentially the most difficult piece of information to encode. This paper is intended to report on the experiences of the Pittsburgh District in acquiring Digital Elevation Models (DEM'S) from the U.S. Geological Survey for the Pine Creek Watershed and the role they played in providing quality ground slope information at a fraction of the cost of other approaches.

ACQUISITION OF DATA

Under the National Mapping Program of the U.S. Geological Survey (USGS), digital elevation data is available at various scales, in several data structures and for selected areas of the conterminous United States. These data are produced and distributed in the form of digital elevation models (DEM's) each corresponding in coverage to the standard USGS 7.5-minute topographic quadrangles, and digital terrain tapes (DTT's) and arc-second DEM's corresponding to 1:250,000-scale topographic maps (Reference 2). In the past, 1:24,000 DEM data has not been available in areas of the Pittsburgh District where GIS work was ongoing or proposed. DTT data had been considered for use in such areas and for studies similar to the Pine Creek Watershed study but it was judged to lack sufficient accuracy for hydrologic modeling in comparison to the resolution of other data being assembled. The availability of such DEM data for the Pine Creek Watershed therefore influenced the Pittsburgh District to undertake its first attempt at using digital topography from the USGS. In October 1986, DEM data was ordered for the five 7.5-minute quadrangles needed to cover the basin, as follows:

Mars, Pennsylvania
Valencia, Pennsylvania
Glenshaw, Pennsylvania
Emsworth, Pennsylvania
Pittsburgh East, Pennsylvania

A standard USGS USGeoData Order Form (FIGURES 1-2) was sent to the National Cartographic Information Center of the USGS at Reston, Virginia identifying the quadrangles by name and indicating that the data should be furnished on 9-track magnetic tapes at a density of 1600 bpi in ASCII format. Shortly after receipt of the order, a technical representative contacted the District to coordinate further in the actual delivery format of the data with regard to physical record length, blocking factor and blocksize. At this point it was expected that the data would be in hand within six weeks or so. However, the actual delivery was not made for approximately five months. This unfortunate delay was explained to be the result of a major change in some facet of computer operations compounded by a quality problem with one of the quadrangles. However, when the data was received in late March 1987, no difficulties were experienced in reading the magnetic tapes delivered. The DEM data was furnished on two magnetic tapes according to the requested specifications and each DEM was contained in a data file of 360,360 bytes stored in 1,024 byte records with a block size of 4,096 bytes. The cost of acquiring this DEM data was $550.00 or $100.00 for each DEM file plus $25.00 for each of two magnetic tapes. For the Upper Sewickley Creek study referenced above, USGS 7.5 minute elevation data was digitized by Pittsburgh District personnel in the form of triangular terrain models covering the entire 102.5 square mile study area over a period of several months. Most of this time was spent in developing the triangular models prior to digitizing. It is estimated that developing similar models for the Pine Creek Watershed would have cost in excess of $5,000 in labor charges. Clearly from the standpoint of cost alone, 1:24,000 DEM data from the USGS is quite a bargain indeed.

CHARACTERISTICS OF DATA

The following material describing the characteristics of 7.5 minute digital elevation models has been extracted from USGS Circular 895-B.

A 7.5-minute DEM has the following characteristics:

* The data consist of a regular array of elevations referenced in the Universal Transverse Mercator (UTM) coordinate system. Elevations randomly located in an irregular array also are allowed in the file structure, but only regular arrays have been produced to date.

* The unit of coverage is the 7.5-minute quadrangle. Overedge coverage is not provided.

* The data are ordered from south to north in profiles that are ordered from west to east.

* The data are stored as profiles in which the spacing of the elevations along and between each profile is 30 m.

* The profiles do not always have the same number of elevations due to the variable angle between true north and grid north of the UTM coordinate system.

The generation of profiles for 7.5-minute DEM's is accomplished using a UTM cartesian coordinate system as a base. The profiles are clipped to the straight line intercept between the four geographic corners of the quadrangle—an approximation of the geographic map boundary (neatline). The resulting area of coverage for the DEM is a quadrilateral, the opposite sides of which are not parallel.

The UTM coordinates of the DEM's four corners (bounds) are contained in a header type record, called a Type A Record, within each DEM file along with other literal and planimetric information. The UTM coordinates of the starting points of each profile are contained in each Type B Record which is the actual vertical profile containing elevation data. These coordinates describe the shape of the quadrilateral and the variable x,y starting position of each profile. Because of the variable orientation of the quadrilateral, in relation to the UTM coordinate system, profiles intersect the east and west neatlines as well as the north and south neatlines. The intersections result in a regular stair-stepped arrangement of the 30-meter nodes just inside the neatline. FIGURE 3 shows the structure of a 7.5-minute digital elevation model. (Reference 3)

USE OF DATA

In order to use the DEM data to produce slope information for hydrologic modeling, a FORTRAN program was written to assemble the five individual DEM data files into one 16-bit raster image file at the 30-meter resolution and also referenced to the UTM coordinate system. This computer program was developed on a DEC VAX 11/730 processor and contains user callable subroutines which are proprietary to ERDAS (Earth Resources Data Analysis Systems), Inc. and which were procured from ERDAS, Inc. by the Pittsburgh District as part of a programming toolkit. The resulting image file is rotated 90 degrees from north and contains 16-bit elevation data in a raster format used by ERDAS, Inc. in image processing and geographic information system file management. By outputing the image file in this rotated state, data processing time was dramatically decreased. This rotation essentially treats movement along a vertical DEM profile as a cooresponding horizontal position in an ERDAS image line since ERDAS image read and write callable subroutines are line oriented. The resulting image elevation file is easily rotated back to north by a standard ERDAS utility called ROTATE. For further detailed information on this program you may contact the authors directly.

Elevation data referenced in meters above the National Geodetic Vertical Datum (NGVD) thus captured in the topographic image file were rescaled to an 8-bit image file for further processing. The ERDAS topographic module was used to create a variety of GIS data files from the elevation image file, such as slope in percent, aspect, contour data and shaded relief image data. These all proved to be of high quality and were used in the Pine Creek Study to either support hydrologic modeling directly as discussed earlier or for report presentation purposes. The absolute accuracy of the elevation data obtained from the DEM's was not evaluated. All DEM data developed to date by the USGS are classified as Level 1 quality, wherein raw elevation data sets have been edited only to remove gross blunders and have a vertical accuracy of 7 to 15 meters. This level of accuracy was not a concern in the Pine Creek Study since the primary analytical use made of the data was the computation of ground slopes. FIGURES 4 through 7 are gray scale images of the 8-bit elevation data, slope variable, aspect variable and a shaded relief map for the Pine Creek Watershed.

CONCLUSIONS

The acquisition and use of USGS 7.5-minute digital elevation models by the Pittsburgh District proved to be generally very rewarding. The initial attempt documented in this paper has set the stage for more involved use of such products in the future and these will be actively pursued. Recent discussions with project management personnel within the National Mapping Division of the USGS revealed some interesting and promising observations of the digital cartographic mapping program. Through FY 1987, the USGS has developed and archived 7.5-minute DEM data for approximately 30 percent of the conterminous United States or for roughly 16,200 quadrangles. The 7.5-minute Level 1 DEM program will continue at a projected pace of 1,500 additional quadrangles per year through FY 1990. It will gradually decline thereafter to give way to contour digital line graph (DLG's) products at the 7.5-minute scale. This new DLG program was started in FY 1987 with the development of 150 quadrangles and has the potential for giving the end user the most positional and vertical accuracy obtainable within the bounds of the data capture process. An additional 350 contour DLG's are programmed for each of FY 1988 and FY 1989. Also just beginning is a three year pilot program to produce 1:100,00 DEM's, 450 in all (Reference 4). These digital topographic products can provide Corps of Engineers analysts with reasonable quality, low cost data bases for a variety of uses such as the one described in this paper. As more Corps offices obtain the appropriate computer equipment and software to efficiently use these and other digital products coming from the USGS and other sources, it is likely that the Federal digital cartographic program will expand as well with the increasing demand. The recent Corps-wide procurement of Intergraph equipment should enable such expansion to occur within the Corps in a coordinated and efficient manner.

REFERENCES

1. U. S. Army Corps of Engineers, Pittsburgh District, "Expanded Flood Plain Information, Upper Sewickley Creek Basin, Westmoreland County, Pennsylvania", Pittsburgh, Pennsylvania, October 1980.

2. McEwen, Robert B.; Calkins, Hugh W.; Ramey, Benjamin S., "Overview and USGS Activities", U. S. Geological Survey, Geological Survey Circular 895-A, Reston, Virginia, 1983.

3. Elassal, Atef A.; Caruso, Vincent M., "Digital Elevation Models", U. S. Geological Survey, Geological Survey Circular 895-B, Reston, Virginia, 1983.

4. Telephone discussions with Mr. Bruce McKenzie, U. S. Geological Survey National Mapping Division, Reston, Virginia, October 1987.

REMOTE SENSING OF SUSPENDED SEDIMENTS OF LAKE CHICOT, ARKANSAS

F. R. Schiebe, J. A. Harrington, Jr., and J. C. Ritchie
USDA-ARS-WQWRL, Durant, OK
New Mexico State University, Las Cruces, NM
USDA-ARS-HL, Beltsville, MD

ABSTRACT

Research concerning the remote sensing of suspended sediment in Lake Chicot waters has been carried out in three stages; (1) laboratory measurements were made under carefully controlled conditions using a large optical tank facility where sediments collected from the lake bed were resuspended, (2) hand-held spectroradiometer measurements were made at 25 nanometer intervals in the visible and near infrared spectrum over the lake at various times providing various concentrations of suspended sediments, and (3) data obtained from 76 environmental satellite (LANDSAT) scenes over a period of 11 years were analyzed and correlated with ground truth data. The hand-held radiometer results show that reflectance in the near infrared region, 700-950 nanometers, is nearly proportional to suspended inorganic sediment at low concentrations. The laboratory results indicate the reflectance to be wave length dependent and to possess definite nonlinear behavior as the concentrations increase. A physical analysis shows this behavior to fit an exponential model. The LANDSAT data shows similar reflectance response to suspended sediments at the same wavelengths with the added benefit of providing a synoptic image.

INTRODUCTION

Lake Chicot is an oxbow lake adjacent to the Mississippi River in southeast Arkansas. It is approximately 12 miles long and 3/4 miles wide. As the largest natural lake in Arkansas it earned an early reputation for its good fishing and recreational value.

Development of a levee system forced the enlargement of the lakes watershed to its present 350 square miles. Construction of a causeway across the lake divided it into two basins, a northern basin comprising about 1/3 of the original lake, and a southern basin which received all of the runoff from the enlarged watershed. Because the watershed is located in a very productive agricultural region, the land, predominantly comprised of clay and fine silts, is very intensively farmed. Large amounts of sediments were produced and the southern basin of the lake was severely impacted. This resulted in chronic high concentrations of suspended sediment while the northern basin remained clear.

In the early 1960's, Congress enacted legislation authorizing the Corps of Engineers to begin planning a method of restoring the lake. Plans were made to construct three structures; a dam to prevent poor quality water from entering the lake, a dam on the outflow to regulate lake levels and downstream discharge, and a combination gravity, flow-pump facility to divert the poor quality water through the levee into the Mississippi River. These structures were placed into operation in the spring of 1985.

Because of the strong agricultural involvement in the problem the Agricultural Research Service, USDA, in 1977 entered into a cooperative agreement with the Corps of Engineers, Vicksburg District to conduct a study of the lake. The objectives of this study were: (1) to characterize the basic limnology of the lake and establish a data base; (2) to develop a process based predictive mathematical water quality model of the lake; and (3) to use the model to establish a strategy to operate the structures to optimize water quality in the lake while allowing sufficient water for other purposes downstream.

The structures and plan were placed into operation during the spring of 1985 and the suspended sediment has not occurred since in large concentrations in the southern basin.

This lake system represented an excellent opportunity to conduct water quality remote sensing studies because of the contrast in water quality between the two basins of the lake and because of the extensive ongoing research being carried out on the lake. For most of the 11 years that the lake has been studied, the site visits have been scheduled to coincide with or within one day of a LANDSAT overpass.

It is the purpose of this paper to document the satellite and limnologica data and interpretations pertaining to the suspended sediment portion of the research.

Acknowledgement is due several persons who have contributed to the project over the years. We especially thank Dr. Joe Nix and Mr. David Honell of Ouachita Baptist University for their site visits and data collection. Mr. James Farrell, Dr. Richard Price, Mr. Ron Goldman, and Mr. Dave Johnson of the Vicksburg District, Corps of Engineers, for their roles in management of Corps activities on the project during the period, Drs. C. M. Cooper and J. R. McHenry, ARS scientists who contributed to the project, Ms. Betty Morrison, ARS Hydrologic Technician who has been primarily responsible for managing the data base and making all calculations required for this paper and Ms. Billie J. Rogers for typing the manuscript.

IN SITU AND LABORATORY STUDIES

In situ research with a portable spectroradiometer was conducted by Ritchie and Schiebe (1979) during 1976 and 1977. This study showed that as the suspended sediment concentration increased the magnitude of the reflectanc also increased and spectral distribution of the reflected solar radiation was shifted toward the red wavelengths. Our early measurements indicated that the best wavelengths to study suspended sediment were the visible red and near infrared in the range 700 to 800 nanometers.

The reflectance in this range was nearly linear at suspended sediment concentrations below about 400 mg 1^{-1}. A linear regression model showed that the data in this range was well related with a regression coefficient, r^2, of 0.88. The reflectance at shorter wavelengths were very sensitive at very low concentrations and the signal seemed to saturate at concentrations greater than about 100 mg 1^{-1}. The longer infrared wavelengths were insensitive and unuseable due to the absorptive properties of the water itself.

READEX FICHE best copy available

Indoor laboratory studies were conducted by Witte et al. (1981) in a 11.6 m^3 water tank located a the Marine Upwelled Spectral Signature Laboratory at the NASA Langley Research Center at Hampton, VA. The water was illuminated with artificial sunlight and upswelled radiance above the water surface was measured by a rapid scanning spectroradiometer.

Sediments from Lake Chicot were collected and resuspended in this facility at concentrations ranging up to 700 mg l^{-1}. These tests, conducted under very controlled circumstances, confirmed the earlier field result that the 700-800 nm wavelength range was the preferred observation range. Further, in an examination of the data presented by Witte, et al., LeCroy (1982) observed that the upwelled reflectance responds exponentially to the suspended sediment concentration.

To formulate LeCroys observation it is suggested here that the MSS band reflectance, R_i, is related to the concentration, c, by

$$R_i = B_i\ (1 - \exp\ (-c/S_i)) \qquad (1)$$

The value of B represents the reflectance saturation level at very high concentrations and the value of S_i represents a concentration parameter equal to the concentration when the reflectance is 63 percent of its saturation value in each band. Both parameters, B_i and S_i are functions of the wavelengths.

LANDSAT STUDIES

Lake Chicot has previously been the object of remote sensing by LANDSAT. LeCroy (1982) examined the patterns of 20 MSS images of the lake covering the period 1972 through 1979 and concluded that LANDSAT imagery "provided an insight into the distribution, possible origin, and seasonal variation turbidity in the lakes." Schiebe et al. (1985) evaluated LANDSAT TM data to monitor the suspended sediment patterns in the lake using a single scene.

Previous progress using MSS data on Lake Chicot was reported by Schiebe et al. (1986) covering the period 1976 to 1979. In this work 33 scenes were analyzed using on site on each of the northern and southern basins of the lake. The measured satellite data was converted first to radiance and further to top of atmosphere (exoatmospheric) reflectance (Robinove, 1982) so that the data set would be on the same basis for all 33 scenes. Correlation coefficients (r^2) resulting from correlating the exoatmospheric reflectance with suspended sediments using a linear regression model were determined and are reported in Table 1.

This research has now been extended to cover the period 1976 through 1986. In all 76 scenes were analyzed on one site on the northern basin and 3 sites on the southern basin making a total of 304 data points in each band.

The exoatmospheric reflectance data for each MSS band was plotted and examined as a function of the measured suspended sediment concentration in the water. As expected the reflectance tended to first increase with concentration and then reach a saturation value as the concentration reached high values. A good deal of scatter was evident in this data.

As a first step to reduce the data to a meaningful basis the reflectance was examined in 25 mg/l "concentration windows." Values of both the average reflectance and the standard deviations were determined for each concentration window. These results are presented in Figure 1 and they clearly show the exponential nature of the reflectance response to suspended sediment in all 4 bands.

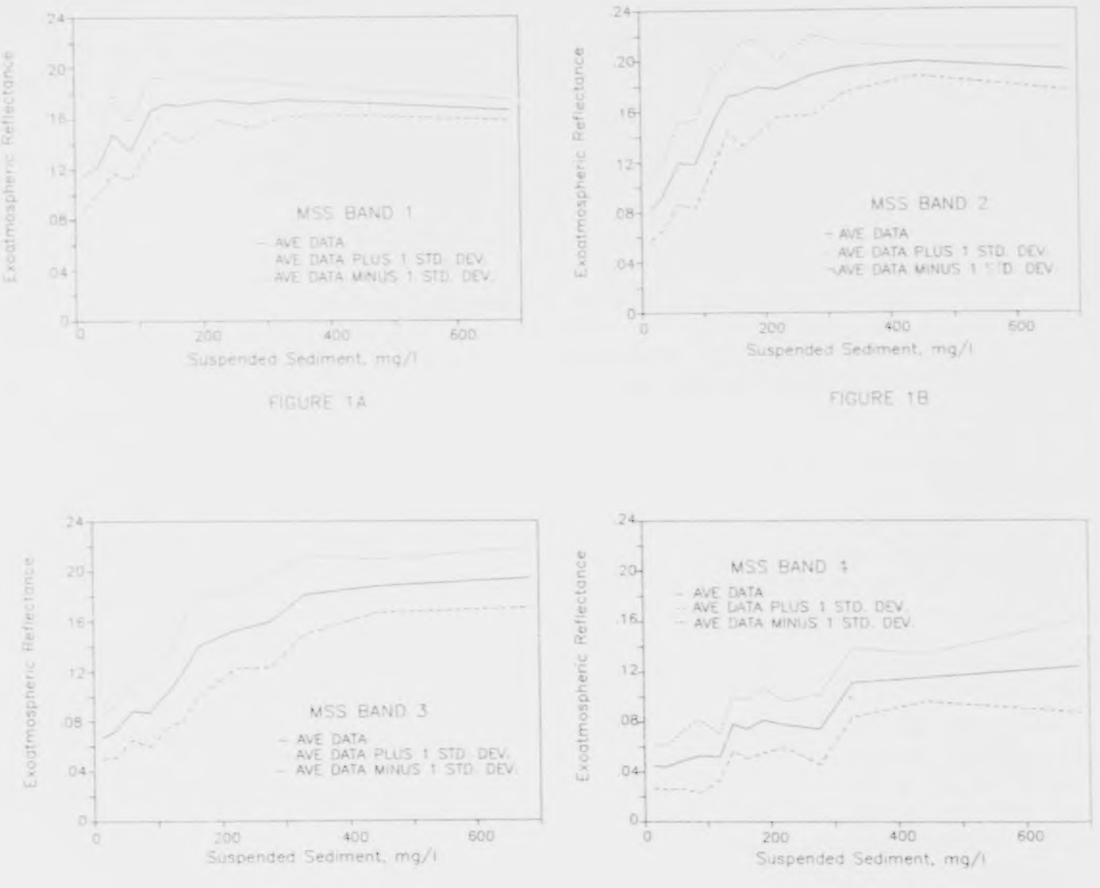


FIGURE 1A

FIGURE 1B

FIGURE 1C

FIGURE 1D

L. CHICOT AVERAGED REFLECTANCE RESPONSE TO SUSPENDED SEDIMENT

It is expected at very low concentration of suspended sediment, that the reflectance would approach near zero values. It has been shown (Cooper, 1983) that the phytoplankton production in Lake Chicot is primarily light limited by the suspended sediment. The necessary nutrients are always present in adequate concentrations. As the suspended sediment settles out to low concentrations in late summer a algal bloom immediately occurs and the emergent backscattered radiance is due to light interaction with the algal cells rather than sediment particles.

If we are attempting to measure only the suspended sediment the light scatters from the algae produces false signal. One method of dealing with this false signal is to add an empirical algae correction term to equation 1. This term should have an amplitude equal to the intersection of the average data on the ordinate and its corrective ability should diminish very quickly as the suspended sediment concentration increases. A exponential term of the form; Ae**(cB/SA) proved to be satisfactory for the purpose. Adding this term to equation 1 gives

$$R_i = A_i e^{(-cB_i/S_iA_i)} + B_i(1-e^{-(e/S_i)}). \qquad (2)$$

An initial parameterization is made using the averaged data in Figure 1. As previously explained A_i is the apparent intersect of the data on the ordinate, B_i is the apparent asymptotic value at high concentrations and S_i is the concentration when the average reflectance is 63 percent of the asymptotic value.

In order to improve the estimates of A_i, B_i, and S_i so that the correlation, r^2, is maximized a computer optimization procedure is used (DeCoursey and Snyder, 1969). The parameters estimated from the average data are used as initial values and the correlations are computed for each step as the parameters are optimized. The parameters are considered optimum when the correlating coefficients are maximized. These correlation values are summarized in Table 1.

TABLE 1

CORRELATION COEFFICIENTS (r^2)

MSS Band	Wavelength range nanometers	Linear model	Est from averaged data	Optimized all data	Optimized truncated data at 25 mg/1
1	500-600	.27	.69	.70	.64
2	600-700	.46	.84	.84	.79
3	700-800	.61	.85	.85	.79
4	800-1100	.40	.71	.72	.64

Since the reflectance data indicated at low concentrations is due to causes other than scattering by sediment particles, an alternate approach to the problem is to eliminate the questionable reflectance data and use equation 1. The method used was to truncate the data set at various sediment concentrations and discard all lower concentrations. The remaining data was used in the computer optimization procedure to optimize the parameters in equation 1. The suspended sediment concentration was methodically truncated and the correlation coefficients determined for each truncation value. These results, shown in Figure 2, indicate that the maximum correlation occurs at a truncation value of about 25 mg/1. These maximum values are included in the last column of Table 1. It is evident that MSS bands 2 and 3 exhibit the best performance.

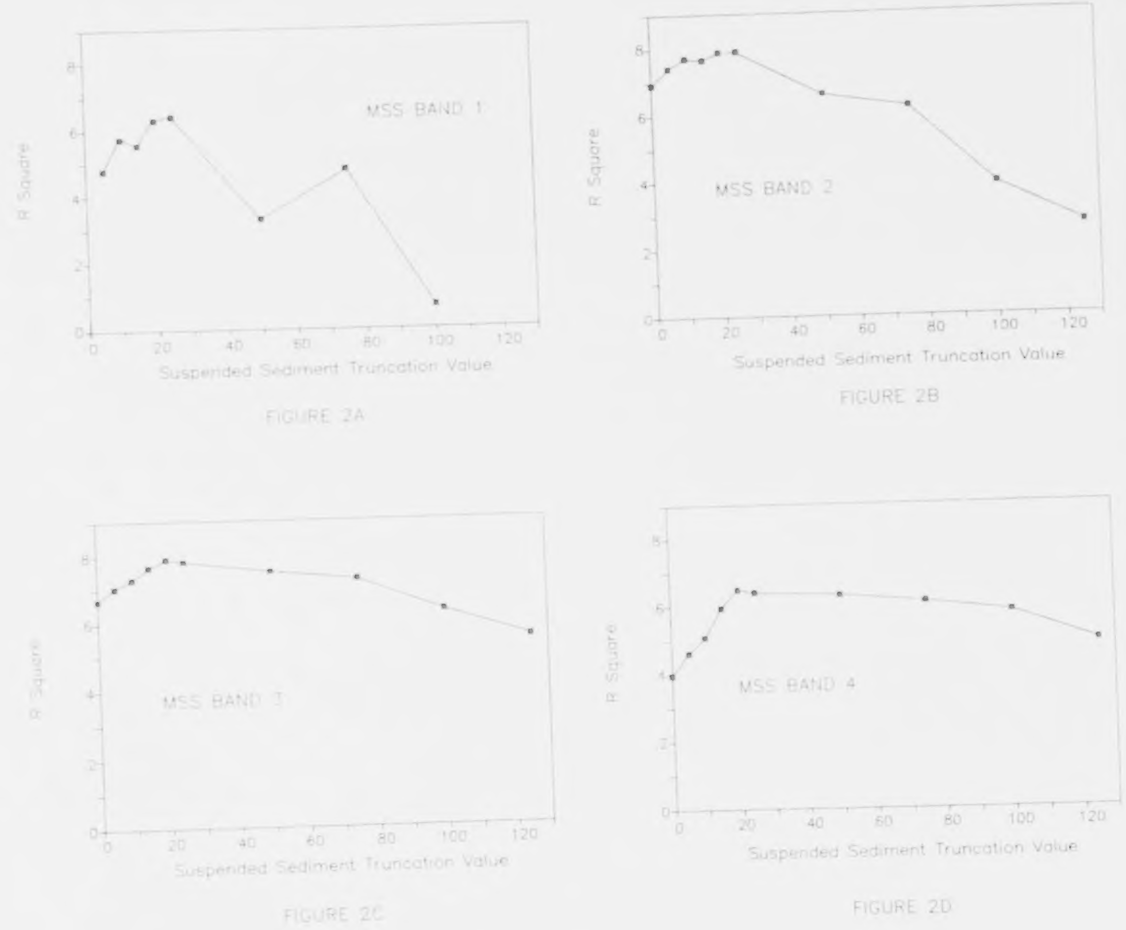


FIGURE 2A

FIGURE 2B

FIGURE 2C

FIGURE 2D

MAXIMIZING CORRELATION COEFFICIENTS BY DATA TRUNCATION

The resulting optimized parameters are given in Table 2 and the optimized function (equation 1) is shown with the entire data set truncated below 25 mg/1 in Figure 3. The optimized parameters for equation 2 using the added correction term are also included in Table 2.

TABLE 2

OPTIMIZED PARAMETERS

	Equation 1		Equation 2		
S	B. unitless	S mg/l	A unitless	B unitless	S mg/l
	.17	26.3	.11	.17	49.4
2	.19	56.5	.08	.20	83.3
3	.18	88.8	.07	.20	157.9
4	.10	95.1	.04	.13	228.0

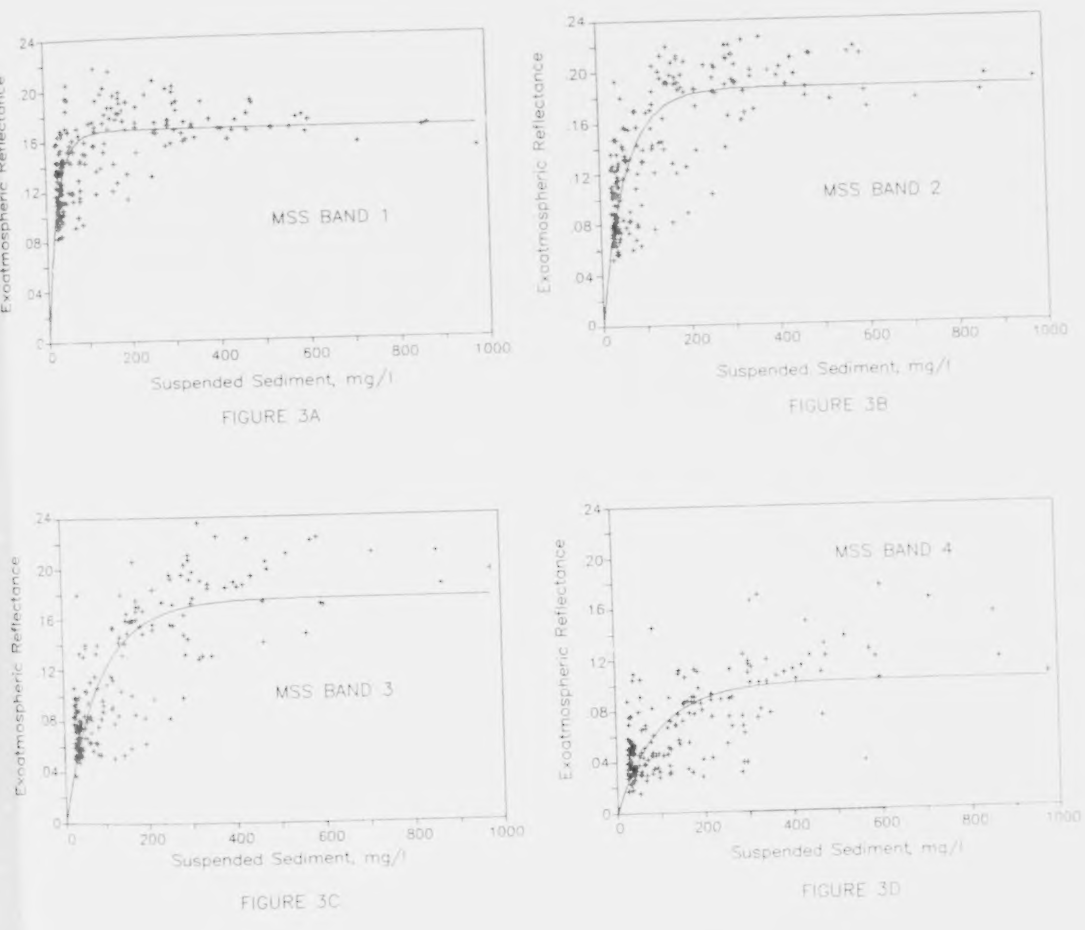


FIGURE 3A

FIGURE 3B

FIGURE 3C

FIGURE 3D

L. CHICOT REFLECTANCE DATA WITH OPTIMIZED PREDICTION FUNCTION

In terms of data correlation, considerable improvement over the linear model was made using the non-linear exponential model with the chlorophyll correction term at low values of suspended sediment concentrations. Some of this improvement was lost in the alternative, but physically more satisfying approach of truncating the data at 25 mg/l. The truncated data, discarded for the present purpose, forms another reflectance data set which is being examined in terms of the chlorophyll content of the water. This, however, is beyond the intended scope of this paper.

Using exoatmospheric reflectance completely disregards any effects that the atmosphere may have on the signal received by the satellite instrument. At present there seems to be no completely satisfactory method to correct for the varying atmospheric effects. Correcting for these effects is especially important when water is the target because, compared with terrestrial observations, the signals are much lower.

CONCLUSIONS

A data set has been assembled using radiance data from 76 LANDSAT scenes from all 5 LANDSATS that have been orbited and corresponding measured suspended sediment data. At low concentrations of suspended sediment the phytoplankton, which were light limited, bloomed and produced interfering signal. This signal was dealt with in two ways. In one approach a correction term was added to an exponential equation relating the suspended sediment data. In a second, the data due to the phytoplankton at low suspended sediment concentrations was eliminated from the data set. The study in general shows a high degree of correlation between reflected radiance and the sediment suspended in surface water.

REFERENCES

COOPER, C.M.; BACON, E.J.; RITCHIE, J.C., "Biological Cycles in Lake Chicot, Arkansas," In Limnological Studies of Lake Chicot, Arkansas, (J. F. Nix and F.R. Schiebe, Eds.), Ouachita Baptist University, Arkadelphia, AR, 1984, pp. 49-61.

DECOURSEY, D.G.; SNYDER, W.M., "Computer-Oriented Method of Optimizing Hydrologic Model Parameters," Journal of Hydrology, No. 9, 1969, pp. 34-56.

LECROY, S.R., "Determination of Turbidity Patterns in Lake Chicot from LANDSAT MSS Imagery," NASA Contractor Report 165870, Langley Research Center, Hampton, VA, 1982.

RITCHIE, J.C.; SCHIEBE, F.R., "Remote Sensing of Suspended Sediments of Lake Chicot, Arkansas," Proceedings American Society of Photogrammetry, 1979, pp. 29-29.

ROBINOVE, C.J., "Computation with Physical Values from Landsat Digital Data," Photogrammetric Engineering and Remote Sensing, Vol. 48, No. 5, May 1982, pp. 781-784.

SCHIEBE, F.R.; RITCHIE, J.C.; BOATWRIGHT, G.O., "A First Evaluation of Landsat TM Data to Monitor Suspended Sediment in lakes," In Landsat-4 Science Characterization Early Results, Vol. IV, NASA Conference Publication 2355, 1985, pp. 337-347.

SCHIEBE, F.R.; RITCHIE, J.C., "Suspended Sediment Monitored by Satellite," In Proceedings of the Fourth Federal Interagency Sedimentation Conference, Vol. 1, Las Vegas, NV, 1986.

WITTE, W.G.; WHITLOCK, C.H.; USRY, J.W.; MORRIS, W.D.; GURGANUS, E.A., "Laboratory Measurements of Physical, Chemical, and Optical Characteristics of Lake Chicot Sediment Waters," NASA Technical Paper 1941, Langley Research Center, Hampton, VA, 1981.

UTILIZATION OF LANDSAT TM FOR FLOODPLAIN ASSESSMENT IN THE TRINITY RIVER, TEXAS, EIS

Tamie Morgan

U.S. Army Corps of Engineers, Fort Worth , TX

and

Jack Stoll

U.S. Army Corps of Engineers
Waterways Experiment Station
Vicksburg, MS

ABSTRACT

The basic purpose of this EIS is to address the impact of regulatory policies on present and future development into the Trinity River floodplain. To do this effectively it was determined that the land use data would be collected and analyzed using computer enhanced digital image processing and mapping techniques.

Three major steps were taken. First, it was necessary to differentiate, map and quantify the variety of land types existing within the study area. A land use classification map was created using Landsat TM digital imagery and the ERDAS (Earth Resources Data Analysis System). Once the land use data base was established, then the quantitative impacts of individual flood events on the land uses were analyzed. Floodplain delineation maps were created from flood profile data and digitized into the data base for each condition analyzed. Finally, we were able to determine the relative economic impact of allowing development into the floodplain and the impact such development would have on future flood events. This was achieved by creating a flood simulation model using a digital topographic data base and the flood profiles provided by the hydraulic analysis.

SESSION III

DEVELOPMENT AND USE OF A WETLAND DATA BASE TO EVALUATE NAVIGATION IMPACTS IN THE ST. MARYS RIVER, MICHIGAN

Donald C. Williams

U.S. Army Corps of Engineer
Detroit District, Detroit, MI

ABSTRACT

The wetland resources of the St. Marys River have been studied to consider navigation impacts on contiguous riverine and palustrine wetlands. In addition to contemporary studies, a historical inventory has been conducted to determined changes over time in relation to changes in water levels and changes in navigation practice. A Geographical Information System - Image Processing System was used to provide an effective means of compiling and organizing the wetland information into a data base. After establishment of the data base, it has been possible to quickly and easily determine the relative abundance and distribution of wetlands types, and to accurately measure wetland changes in project areas of the St. Marys River.

Wetland types and areas were determined by interpretation of aerial photos from the summer seasons 1939, 1953, 1964, 1978, 1982, 1984, and 1985. The scales of the photos ranged from 1:12,000 to 1:62,500. Wetlands to one-half mile inland from the riverbank incorporated wetlands that could be influenced by changing water levels, ice, or navigation effects from the proposed project. Wetland areas were quantified for each date of aerial photo by contractors of the U.S. Fish and Wildlife Service, National Wetland Inventory, St. Petersburg, Florida. Ground truth was also obtained by USFWS contractors. Interpretations were completed with an analog stereo plotter. The plotter established geometric control and was used to correct any inaccuracies found in the photos. Wetlands were classified and mapped on five U.S. Geological Survey quadrangles. The polygons formed by the wetland boundaries were converted into areas, and reported in tenths of acres by the USFWS Wetland Analysis and Measurement Mapping System Software. After review and correction, the maps were digitized and placed in the USF&WS MOSS system. They were then converted to files on 9-track magnetic tapes in the ELAS image processing format.

The products were analyzed using Earth Resources Data and Analysis System (ERDAS) Image Processing and Geographic Information System software at the Detroit District. This allowed rapid measurement of wetland type and acreage changes and analysis of their relationship to river channel characteristics, changes in water levels, and altered navigation practices.

INTERPRETATION OF COASTLINE CHANGE IN LAKE MICHIGAN, BERRIEN COUNTY, MICHIGAN USING DIGITIZED AERIAL PHOTOGRAPHY

Karen H. Lee
Charles L. Thompson
U.S. Army Corps of Engineers, Detroit, Michigan

ABSTRACT

The feasibility of using digital analysis of aerial imagery for coastline mapping in the Great Lakes will be investigated. Scan-encoding techniques were used to gain digital density data from three multi-temporal aerial photographs (1:6000) from a high erosion area located along the southeast shoreline of Lake Michigan. Comparisons will be made between the scan-encoded and original photographs to determine whether automatic data processing methods can provide a reliable method for mapping and monitoring large areas of coastline.

STUDY AREA

The region chosen for investigation is located at the southeastern end of Lake Michigan in Berrien County, Michigan, south of the City of St. Joseph in the community of Shoreham. The coastline in the vicinity of Shoreham is characterized by steep bluffs, approximately 70 feet high, comprised of alluvium, glacial outwash and lacustrine silts, sands and gravels.

This particular site was chosen for several reasons. Most importantly, the region has a long history of erosion and has been designated as a "high risk" erosion area by the Michigan State Department of Natural Resources. A high risk erosion area is defined as one in which the long term average erosion rate is equal to or greater than one foot per year. Using historical aerial photography, dated 1938 through 1973, the long term average erosion rate for this area has been calculated to be on the order of five feet per year. For many property owners the loss of their homes was the price paid for choosing to live in this area. Episodic erosion events have occurred in this area in which approximately 80 feet of bluff recession along a short reach resulted from a two day storm. With such a dramatic erosion history, both shoreline and bluff crest recession would be easily observable; therefore, the region appeared well suited for both short and long term erosion investigations.

The Detroit District is responsible for the operation and maintenance of the Federal navigation structures at the St. Joseph harbor which is approximately five miles to the north of the study area. To mitigate erosional effects associated with the blockage of littoral drift by the navigation structures, the District has maintained a beach nourishment at St. Joseph since 1976. Basically, the beach nourishment program involves the periodic placement of an amount of sand on the downdrift, or south side of the structures which is equal to the volume of material blocked on the updrift side. To determine the effectiveness of the nourishment program, the District monitors the coastline under the influence of the navigation structures. Shoreham and the study area are located within the zone of influence.

The Shoreham study area was selected to develop general techniques which could be used to identify erosion sensitive areas and to quickly and accurately determine erosion rates along extended reaches of coastline. Monitoring coastline conditions, whether for a specific purpose or general reconnaissance, is presently based primarily on interpretation of color aerial photography and photogrammetric mapping. The process of photo interpretation is time consuming, expensive, and temporal comparisons between air photo flights are laborious. Still, color aerial photographs provide dramatic documentation of shoreline conditions. The photogrammetric maps (1:1200) have a horizontal accuracy of 1 foot (+ or -). This degree of accuracy is necessary for monitoring episodic events or short term recession/progradation over a season to several years. Because of the ground survey cost involved, only approximately 30 miles of shoreline, at scattered locations, are mapped during any one year. Identification of high risk erosion areas and measurement of long term erosion rates could be accomplished with a horizontal accuracy of 5 feet (+ or -). This degree of accuracy is well within the resolution obtainable from the digitized photography. The use of digitally encoded aerial photography presents a potential cost effective method for data storage and analyses of large libraries of photographs.

METHODS

Three vertical aerial photographs were selected for comparison and cover a five year time span, dated April 1980, April 1983, and April 1985. The photographs, first-generation 9-by-9-inch color prints (1:6000), were digitally encoded into raster image files with an EIKONIX Series 850 Digital Imaging Camera System[1]. The EIKONOIX system converts illuminated images or objects into digital data through a linear sensor array which spatially resolves the transmitted or reflected light into individual picture elements (pixels). Each of the photographs were scan encoded in three-channel color (red, green, blue). Each photograph was also scanned three times at varying degrees of resolution (DPI-dots per inch) to provide information regarding the pixel resolution necessary for effective erosion monitoring and still have optimum computer storage considerations. The resulting pixel sizes from the three scans represent areas of 2, 3.5, and 5 square feet. The amount of computer storage space required for each of these scans are approximately 15.2, 3.8, and 2.4 megabytes respectively.

---

1. EIKONIX is a registered trademark of Eastman Kodak Company.

The estimation of land cover types using digitized photographs makes the assumption that land use can be discriminated by differences in film density. Problems arise from the decreased reduction of density toward the outer edges of a photograph (vignetting or lens fall-off) which can result in different film densities for the same cover type. The study area is located near-center on all three controlled aerial photographs and probably will minimize the effects of vignetting.

Each photograph will be evaluated separately because color balance, sun angle, and atmospheric conditions differ among the multi-temporal photography. Cover types on one photograph do not exhibit the same color and tone as the related feature on another. Wave conditions, water depth, turbidity, and sun glint contribute greatly to tonal differences on the photographs which include the nearshore zone. The classification accuracy of the beach and bluff is expected to be hindered by the spectral variability which is characteristic of the material that compromise them. Shadows and gaps within the vegetation on the photographs are also expected to increase spectral variability in the digital classification of the study area (Snook, et al., 1987). Consistent patterns have been found in vegetation mapping using digitized aerial photography in land cover classes which are uniform and easily identified, such as water and sand. These two particular classes tend to align closely along one or more diagonal straight lines. The use of uncalibrated data may also require that many more spectral signatures be used for each category in the digital classification to account for overall film density variations (Scarpace, et al., 1981). It is anticipated that the land cover/use classes to be extracted in this study will include: water, sand, dune vegetation, residential/roads, shore structures, agricultural, and forested areas.

A photogrammetrically mapped mylar (1:1200) from the 1985 aerial survey will be used to geo-reference the 1985 photograph with the District's image processing system. The other two photographs will be referenced to these 1985 established control points and thereby allow a matrix to be generated later in which changes between cover classes can be detected. Classification accuracy will be measured against a sample of points interpreted and measured manually from the photographs. Digital image enhancements will be utilized to minimize the tonal differences between the three photographs and several classification schemes will be attempted to produce the best results.

REFERENCES

SCARPACE, F.L.; QUIRK, B.K.; KIEFER, R.W.; WYNN, S.L.; "Wetland Mapping from Digitized Aerial Photography," Photogrammetric Engineering & Remote Sensing, Vol. 47, No. 6, June 1981, pp. 829-838.

SNOOK, P.W.; WINTERBERGER, K.C.; MERRITT, N.E.; CZAPLEWSKI, R.L.; "Comparison Between Digital and Manual Interpretation of High Altiude Aerial Photographs", Photogrammetric Engineering & Remote Sensing, Vol. 53, No. 5, May 1987, pp.531-534.

TURNER, B.J.; THOMPSON, D.N.; "Barrier Island Vegetation Mapping Using Digitized Aerial Photography", Photogrammetric Engineering & Remote Sensing, Vol. 48, No. 8, June 1981, pp.829-838.

THE USE OF DIGITAL HABITAT MAPS IN STUDYING LANDSCAPE PROCESSES: EFFECT OF SPATIAL FACTORS ON LAND LOSS

Scott G. Leibowitz
Center for Wetland Resources
Louisiana State University
Baton Rouge, LA 70803

and

John M. Hill
Remote Sensing and Image Processing Lab
Louisiana State University
Baton Rouge, LA 70803

ABSTRACT

Southern Louisiana, which contains 40% of the nation's coastal wetlands, is in a state of decline. Land is being converted to open water at an estimated rate of 100 km^2 per year. Both natural and human-induced factors have been suggested as contributing to this problem. It has been difficult to sort out the various factors, however, because of the complexity of this landscape.

A geographic information system containing 10 m resolution digital data was used to examine the effect of factors such as site and habitat type on land loss. In addition, spatial measures of proximity and density were included. Combining these data with spatial statistics has allowed specific land loss hypotheses to be tested. Results indicate that land loss is not a uniform, homogeneous process which acts in a similar fashion throughout the state; rather, hot spots with high loss rates account for a large percent of land loss.

INTRODUCTION

Forty-one percent of the nation's coastal marshes are found in Louisiana (Turner and Gosselink 1975). The productivity of Louisiana's coastal zone is a valuable economic asset: 30% of the nation's fishery landings come from this area (U.S. Department of Commerce 1986); the region accounts for 40-65% of the nation's annual fur harvest (Larson et al. 1980); and coastal marshes and swamps provide invaluable protection against storm generated flooding and erosion (Gosselink et al. 1974). The Louisiana coast is also rich in oil and gas: more than 65% of the state's multibillion dollar oil and gas revenues come from this coastal zone (Production Audit Section, Office of Conservation, Louisiana Department of Natural Resources).

Studies over the last decade have shown that the Louisiana coast is in a state of decline (Adams et al. 1976, Craig et al. 1979, Gagliano and van Beek 1970, Gagliano et al. 1981, Sasser et al. 1986). Conversion of wetland to open water is occurring at an estimated rate of 100 km^2 per year (Gagliano et al. 1981). Both natural and human-induced factors have been suggested as contributing to this condition (Table 1). It has been difficult to test these various hypotheses, however, because of the complexity of this landscape.

TABLE 1 - FACTORS POSSIBLY CONTRIBUTING TO LAND LOSS.

Natural Processes

- Loss of sediment through delta abandonment
- Subsidence from isostatic adjustment or sediment compaction
- Storm erosion
- Sea level rise

Human-Induced Processes

- Loss of sediments from leveeing of the Mississippi River
- Use of control structures to prevent abandonment of the Mississippi
- Reduction in sediment load through upstream alterations
- Impoundment and drainage of wetlands
- Subsidence from fluid withdrawal
- Alteration in hydrology and sedimentation from canals
- Saltwater intrusion due to canals

[References: Craig et al. 1979, Gosselink and Baumann 1980, Mendelssohn et al. 1983, Morgan 1967]

A two year study of land loss, funded by the Minerals Management Service, was recently completed. As part of this project, a geographic information system (GIS) containing 10 m resolution, digital data was constructed to study land loss. Our goals were to: (1) develop a methodology for studying landscape level processes; (2) determine the spatial pattern of land loss in coastal Louisiana; and (3) assess the relative importance of natural versus cultural processes as causes of land loss. Our methodology was to use this GIS to define areas of land loss for three study areas; to compare land loss rates by site, habitat type, and change in salinity; and to determine whether specific spatial features, e.g., canal, affected land loss rates. A complete description of the study is provided in Leibowitz and Hill (1987).

METHODS

Three areas in southern Louisiana were chosen for analysis (Figure 1). The Cameron study area, in the western portion of the state, is outside of the direct influence of the Mississippi River in an area known as the Chenier Plain. The Terrebonne site contains the mouth of the Atchafalaya River, which currently captures 30% of the Mississippi River's flow. The Lafourche study area is the easternmost of the sites. It is located adjacent to Bayou Lafourche, a distributary of the Mississippi River abandoned in geologically recent time; it is therefore in a stage of advanced disintegration.

Digital habitat maps for the three study areas were obtained for 1956 and 1978 from the Coastal Management Division of the Louisiana Department of Natural Resources. These data were derived from habitat maps of the Louisiana coast produced by Coastal Environments, Inc., of Baton Rouge (Wicker 1980, 1981). The maps were prepared at a scale of 1:24,000 and digitized by the U.S. Fish and Wildlife Service. The data were then converted to 10 m grid format. The GIS was constructed using the Earth Resources Laboratory Applications Software (ELAS) developed by the NASA/Earth Resources Laboratory (NASA 1986) and modified by the Remote Sensing and Image Processing Laboratory at Louisiana State University.

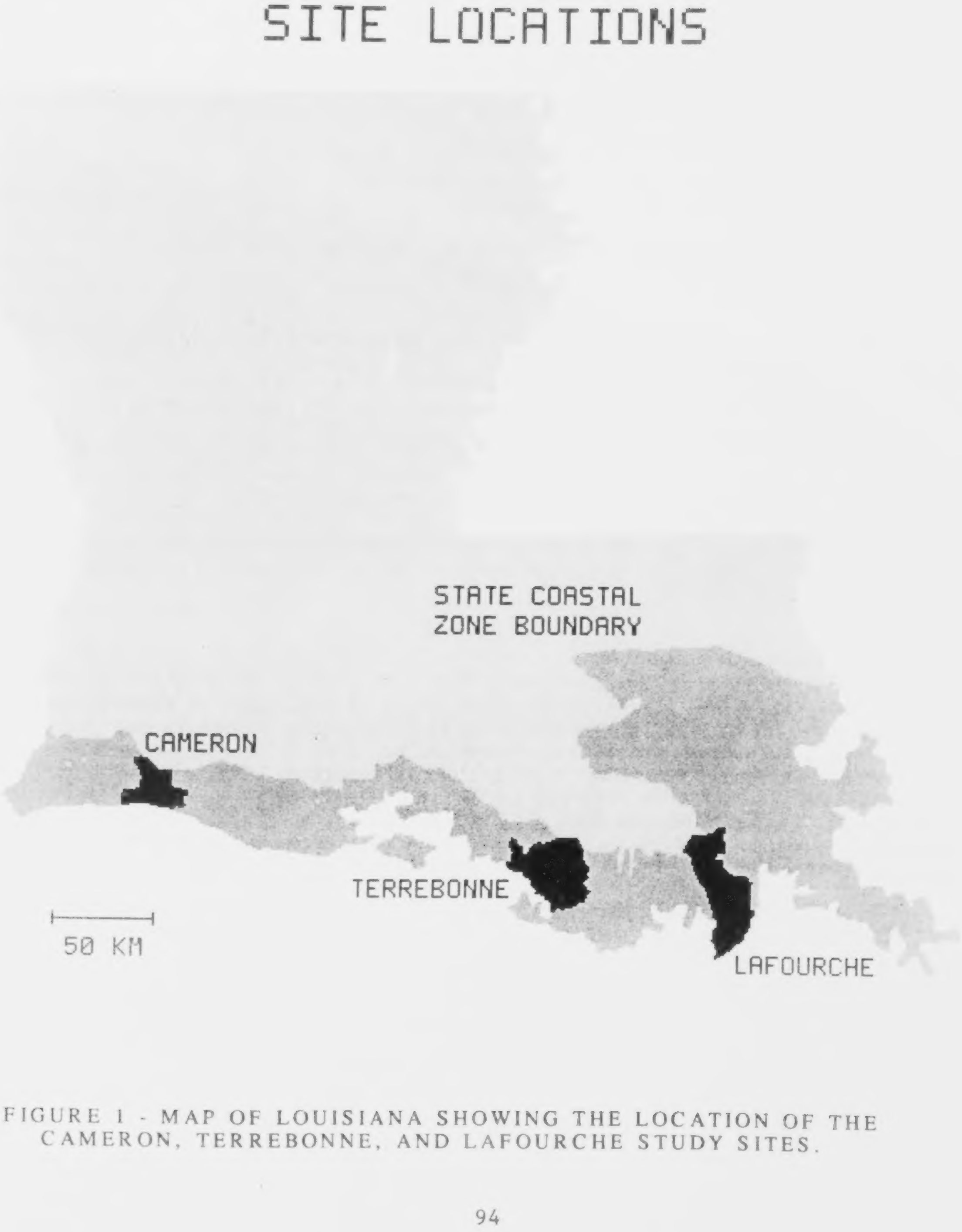

SITE LOCATIONS
STATE COASTAL
ZONE BOUNDARY
CAMERON
TERREBONNE
LAFOURCHE
50 KM

FIGURE 1 - MAP OF LOUISIANA SHOWING THE LOCATION OF THE CAMERON, TERREBONNE, AND LAFOURCHE STUDY SITES.

Data were later analyzed using the SAS statistical package (SAS Institute, Inc. 1985a,b).

The GIS contained nine aggregated land habitats and four aquatic classes (Leibowitz and Hill 1987): agriculture, beach/dune/reef, fresh marsh, mudflat, saline marsh, spoil, swamp, upland, urban/industrial, canal, coastal open water, inland open water, and natural channel. In addition, presence of freshwater/saltwater vegetation boundaries for both years allowed each cell in the GIS to be classified according to its change in salinity: cells which were fresh in 1956 and fresh in 1978, areas that were fresh in 1956 but saline in 1978, cells that changed from saline to fresh between 1956 and 1978, and areas that remained saline during the 22 year period (Figure 2).

For this study, land loss was defined as any cell that was land in 1956 but changed to water by 1978 (Figure 3). Loss rates were then compared by site, habitat type, and change in salinity. To examine whether proximity to various spatial features affected land loss, equal distance contours were "grown" around the feature of interest (Figure 3). The spatial features that were examined included canal and spoil, natural channel (rivers, streams, and bayous), inland open water, and major channel (Lake Calcascieu/Calcascieu Shipping Channel, the Atchafalaya River, and Bayou Lafourche for the Cameron, Terrebonne, and Lafourche sites, respectively). The spatial densities of various features were also examined to determine their effect on land loss (e.g., area of canal and spoil per square km).

RESULTS AND DISCUSSION

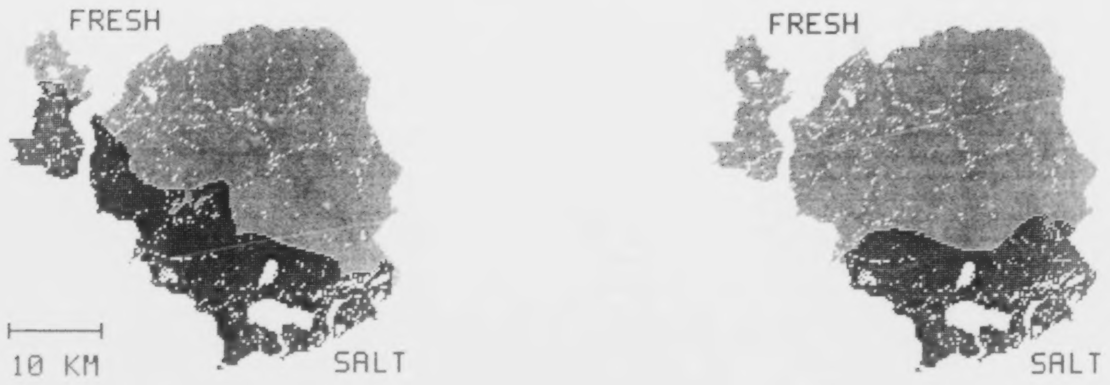
The GIS described in this paper, combined with spatial statistics, has provided valuable information on the pattern of land loss within coastal Louisiana. A summary of these findings follows (the complete results may be found in Leibowitz and Hill 1987).

1. Rates of land loss were consistent with the geology of the site. The lowest rate of loss was at the Terrebonne site (14%), which currently contains an active sediment source (the Atchafalaya River). The Lafourche site, which is bordered by a recently abandoned distributary, had the highest rate (21%). The Cameron site, in the Chenier Plain, had an intermediate loss rate (17%).

2. Marsh habitats accounted for most land loss at all three study areas. Loss of marsh (both fresh and saline) accounted for 85-95% of all land loss. Each of the other habitat types contributed less than 5% of the loss at a site (except for agriculture at Lafourche, which accounted for 8% of the loss there).

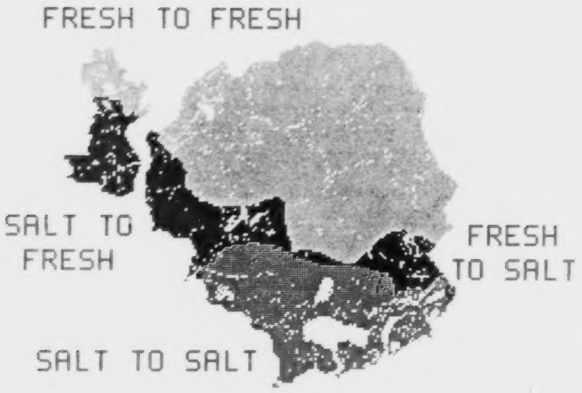
3. The major form of land loss is within the marsh interior, and not shoreline loss. Conversion of land to inland open water accounted for 70-93% of all loss. Loss of shoreline (coastal erosion) contributed less than five percent at all three sites. Direct loss from canal construction was low at Cameron (3%), but more significant at Terrebonne and Lafourche (14-15%).

4. Saltwater intrusion is not thought to be the major cause of land loss at the Terrebonne site, although this could not be ruled out for the Cameron and Lafourche sites. At Cameron and Lafourche, loss was significantly higher in the areas of increasing or high salinity (fresh to salt and salt to salt) than in the areas of low or decreasing salinity (fresh to


FRESH
10 KM
SALT
FRESH
SALT

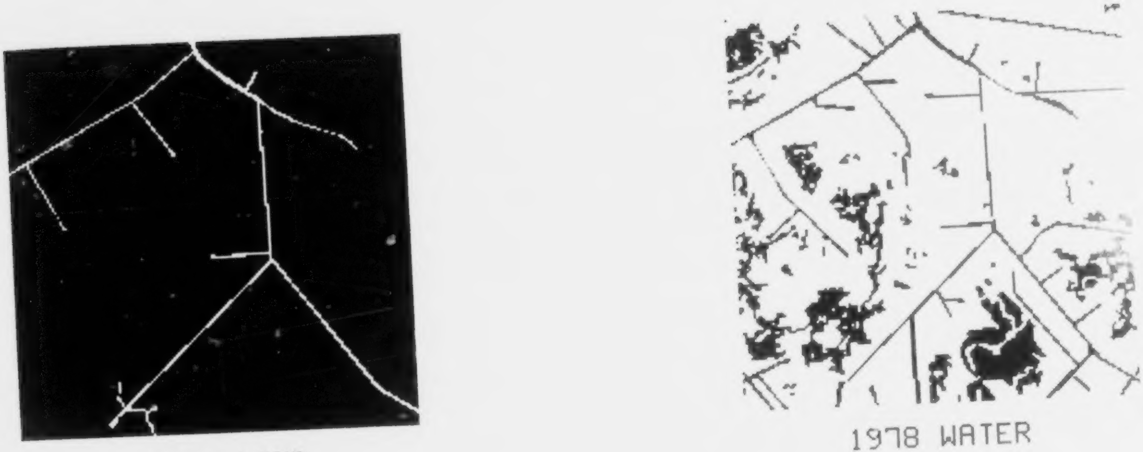
1956

1978


FRESH TO FRESH
SALT TO FRESH
FRESH TO SALT
SALT TO SALT

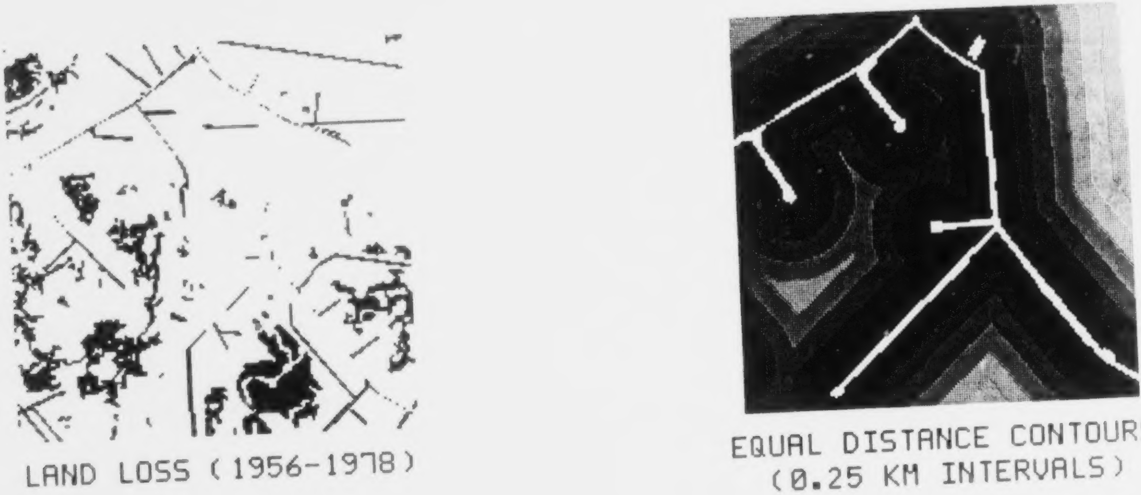
CHANGE (1956 TO 1978)

FIGURE 2 - EXAMPLE OF SALINITY CHANGES BASED ON 1956 AND 1978 VEGETATION ZONES FOR THE TERREBONNE STUDY SITE.



1956 LAND

1978 WATER



LAND LOSS (1956-1978)

EQUAL DISTANCE CONTOURS (0.25 KM INTERVALS)

FIGURE 3 - ILLUSTRATION OF LAND LOSS AND EQUAL DISTANCE CONTOURS.

fresh or salt to fresh). Land loss was, therefore, correlated with saltwater intrusion. Thus, it was not possible to disprove this as a causative factor at these two sites. At the Terrebonne site, however, land loss was highest in areas that remained fresh for the 22 year duration (fresh to fresh), with no significant difference between this category and the areas of increasing or high salinity (fresh to salt or salt to salt). Further, these values were all significantly lower than the values found at Cameron and Lafourche. Therefore, it is concluded that saltwater intrusion is not the major cause of land loss at the Terrebonne site.

5. Land loss at the Terrebonne site may be the result of a recent process. For the Cameron and Lafourche sites, a large portion of loss is located adjacent to inland open water. Since land loss prior to 1956 would be classified as inland open water, this may represent the expansion of pre-existing land loss areas. At Terrebonne, however, this was not observed, indicating that loss at this site may have only recently been initiated.

6. Nearness to a major sediment source reduces land loss. Plots of cumulative loss versus distance to major sediment source show that most loss occurs at distances far from these features (this is also true for Bayou Lafourche, even though it is an abandoned distributary). For an active sediment source such as the Atchafalaya River, loss rates were greatly reduced to a distance of 12 km.

7. A large proportion of the land loss at the three study sites occurs in areas with canal densities near zero. Cumulative curves of percent land loss indicate that 40-80% of all loss occurred in areas with nearly zero canal and spoil density. Canal and spoil appear to cause the most damage when they are added to areas of solid marsh.

8. Land loss is not a uniform, heterogeneous process; rather, "hot spots" of high loss have been found. A statistical model that included site, habitat type, salinity change, distance to coastal shoreline, and the site interactions had an r-square of 0.24; thus, 75% of the variation in land loss was not accounted for. The outliers, however, were spatially clumped, and were associated with areas of high loss. These hot spots account for 43% of the land loss, although they represent only 12% of the study area. Including the hot spots in the statistical model raised the r-square to 0.75. The cause of these hot spots could not be determined.

CONCLUSIONS

The major use of geographic information systems has been in mapping the spatial distribution of some parameter of interest, such as optimal locations for hazardous waste sites. The full power of these systems will not be realized, however, until they are merged with spatial statistics, thus allowing specific hypotheses to be tested. This would be especially valuable for a complex landscape such as the Louisiana coast, where causative factors may not be obvious and where multiple effects can occur. For example, it has long been assumed that oil and gas canals could cause land loss by introducing saline water into freshwater regions, consequently killing the vegetation. It has been shown that this is not so, however, at least for the Terrebonne site. Managing this area for saltwater intrusion (e.g., constructing impoundments or emplacing weirs) could actually exacerbate land loss by reducing sediment input. Combining a GIS with spatial statistics, as discussed within this paper, allows the analyst to test assumptions such as this before a plan is implemented. This should lead to more effective environmental management.

ACKNOWLEDGEMENTS

This research was funded by the U.S. Dept. of the Interior, Minerals Management Service, New Orleans, LA, Contract No. 14-12-0001-30252, "Outer Continental Shelf Development and Potential Coastal Habitat Alteration," R.E. Turner, Project Manager.

REFERENCES

ADAMS, R.D.; BARRETT, B.B.; BLACKMON, J.H.; GANE, B.W.; MCINTIRE, W.G., "Barataria Basin: Geologic Processes and Framework," Sea Grant Publication No. LSU-T-76-006, Center for Wetland Resources, Louisiana State University, Baton Rouge, LA, 1976, 117 pp.

CRAIG, N.J.; TURNER, R.E.; DAY, J.W., JR., "Land Loss in Coastal Louisiana (U.S.A.)," Environmental Management 3(2): 133-144, 1979.

GAGLIANO, S. M.; MEYER-ARENDT, K.J.; WICKER, K.M., "Land Loss in the Mississippi River Deltaic Plain," Transactions of the Gulf Coast Association of Geological Societies 31: 295-300, 1981.

GAGLIANO, S.M. AND VAN BEEK, J.L., "Geologic and Geomorphic Aspects of Deltaic Processes, Mississippi Delta System," Coastal Studies Institute Report 1, Louisiana State University, Baton Rouge, LA, 1970, 140 pp.

GOSSELINK, J.G. AND BAUMANN, R. H., "Wetland Inventories: Wetland Loss Along the United States Coast," Z. Geomorph. N.F. 34: 174-187, 1980.

GOSSELINK, J.G.; ODUM, E.P.; POPE, R.M., "The Value of the Tidal Marsh," LSU-SG-74-03, Center for Wetland Resources, Louisiana State University, Baton Rouge, LA, 1974, 30 pp.

LARSON, D.K.; DAVIS, D.W.; DETRO, R.A.; DUMOND, P.B.; LIEBOW, E.B.; MOTSCHALL, R.M.; SORENSEN, D.P.; GUIDROZ, W.S., "Mississippi Deltaic Plain Region Ecological Characterization: A Socioeconomic Study. Volume 1: Synthesis Papers," FWS/OBS-79/05, Office of Biological Services, U S. Fish and Wildlife Service, Washington, D.C., 1980, 368 pp.

LEIBOWITZ, S.G. AND HILL, J.M., "Spatial Analysis of Louisiana Coastal Land Loss," in Turner, R.E. and Cahoon, D.R., "Causes of Wetland Loss in Coastal Central Gulf of Mexico," Final Report to Minerals Management Service, 1987 (in press).

MENDELSSOHN, I.A.; TURNER, R.E.; MCKEE, K.L., "Louisiana's Eroding Coastal Zone: Management Alternatives," J. Limnol. Soc. Sth. Afr. 9(2): 63-75, 1983.

MORGAN, J.P., "Ephemeral Estuaries of the Deltaic Environment," in Lauff, G.H., "Estuaries," Publication No 83, American Association for the Advancement of Science, Washington, D.C., 1967, pp. 115-120.

NASA, "Earth Resources Laboratory Applications Software Volume II: User Reference," Report No. 183, Earth Resources Laboratory, National Space Technology Laboratories, National Aeronautics and Space Administration, NSTL Station, MS, 1986.

SAS INSTITUTE, INC., "SAS User's Guide: Basics," Version 5 Edition, SAS Institute, Inc., Cary, NC, 1985(a).

SAS INSTITUTE, INC., "SAS User's Guide: Statistics," Version 5 Edition, SAS Institute, Inc., Cary, NC, 1985(b).

SASSER, C.E.; DOZIER, M.D.; GOSSELINK, J.G.; HILL, J.M., "Spatial and Temporal Changes in Louisiana's Barataria Basin Marshes, 1945-1980," Environmental Management 10(5): 671-680, 1986.

TURNER, R.E. AND GOSSELINK, J.G., "A Note on Standing Crop of *Spartina alterniflora* in Texas and Florida," Contributions in Marine Science 19: 113-118, 1975.

U.S. DEPARTMENT OF COMMERCE, "Fisheries of the United States, 1985," Current Fishery Statistics No. 8380, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Washington, D.C., 1986, 121 pp.

WICKER, K.M., "Mississippi Deltaic Plain Region Ecological Characterization: A Habitat Mapping Study. A User's Guide to the Habitat Maps," FWS/OBS-79/07, Office of Biological Services, U.S. Fish and Wildlife Service, Washington, D.C., 1980.

WICKER, K.M., "Chenier Plain Region Ecological Characterization: A Habitat Mapping Study. A User's Guide to the Habitat Maps," Louisiana Coastal Resources Program, Louisiana Department of Natural Resources, Baton Rouge, LA, 1981.

INFLUENCE OF LAND COVER ON BARRIER ISLAND EROSION AS DETERMINED FROM PHOTOGRAPHIC AND DIGITAL IMAGERY

L. Dorsey Worthy, Jr.
Research Assistant

John M. Hill
Associate Director

Remote Sensing and Image Processing Laboratory

and

Irving A. Mendelssohn
Associate Professor

Wetlands Soils and Sediments Laboratory

Center for Wetlands Resorces
Louisiana State University
Baton Rouge, LA

ABSTRACT

The Louisiana barrier islands consist of a series of highly dynamic, low topographic relief barrier strands. Due to a number of factors, including the unconsolidated state of underlying sediments, an impoverished sand supply, and the frequency of major storm events, these islands are undergoing rapid rates of erosion. Because of their value in protecting inland marsh areas, Timbalier Island and the Isles Dernieres have been targeted for major stabilization efforts. Past efforts at barrier island management have concentrated primarily on beach nourishment and dune stabilization. However, other factors, such as the location and extent of island vegetation assemblages, may be of greater importance in influencing barrier island erosion rates. In this study, time series color-infrared aerial photographs were used to create a digital database. These data were then used to determined the location and degree of change relative to the proximity, type, and extent of land cover categories over a seven year period. Aerial MSS and Landsat TM scenes were classified using both supervised and unsupervised techniques. These were georeferenced to the manually derived photographic database in order to compare their usefulness as data sources for determining barrier island cover categories and for monitoring erosion rates. Preliminary results indicate that, for these islands, the back barrier marsh areas are more important than beach or dune areas in slowing erosion rates.

PHOTOGRAMMETRIC MEASUREMENT OF 42-TON DOLOS MOTIONS ON THE OUTER BREAKWATER AT CRESCENT CITY, CALIFORNIA

Thomas R. Kendall
San Francisco District
U.S. Army Corps of Engineers
San Francisco, CA

Richard B. Davis & Jeff Leach
Richard B. Davis Co.
Crescent City, CA

ABSTRACT

Precise remote measurements of post-contruction movements of 42-ton dolosse on the outer breakwater at Crescent City, California have been obtained using photogrammetric techniques. Using periodic aerial photography taken at low tide, several accurate, permanent records of all visible dolosse have been produced. This paper describes the methods used and results obtained in this monitoring effort along with the application of these results to a Corps' study whose objective is to develop structural design criteria for the dolos concrete armor unit.

INTRODUCTION

An alarmingly high incidence of breakage in large (greater than 20 ton) dolos armor units both in the U.S. and abroad has led the Corps of Engineers to initiate a field data collection program on the behavior of large dolosse with an ultimate objective to develop a structural design procedure for the armor unit. The study elements include field monitoring as well as physical modeling and numerical simulation. The field monitoring includes internal instrumentation as well as more remote monitoring of 42-ton dolosse on the outer breakwater at Crescent City, California.

This paper focusses on the application of aerial photography and photogrammetry to monitoring of dolos motions. Several other papers

(Domurat and Howell, 1984; Wood, et al., 1985; Kendall et al., 1985; and Howell, 1986) provide more information on the other elements of this extensive monitoring program, including the use of internal strain gages and accelerometers in select dolosse to measure dynamic and static structural responses.

The monitoring site is shown in Figure 1. The Crescent City Outer Breakwater consists of a main leg approximately 3700 feet in length and an easterly extension (dogleg) approximately 1000 feet long. The dolos section has a design wave height of 35 feet and was initially comprised of 246 40-ton unreinforced dolosse distributed along the last 230 feet of the main stem. These were placed in 1974 and the majority had broken before

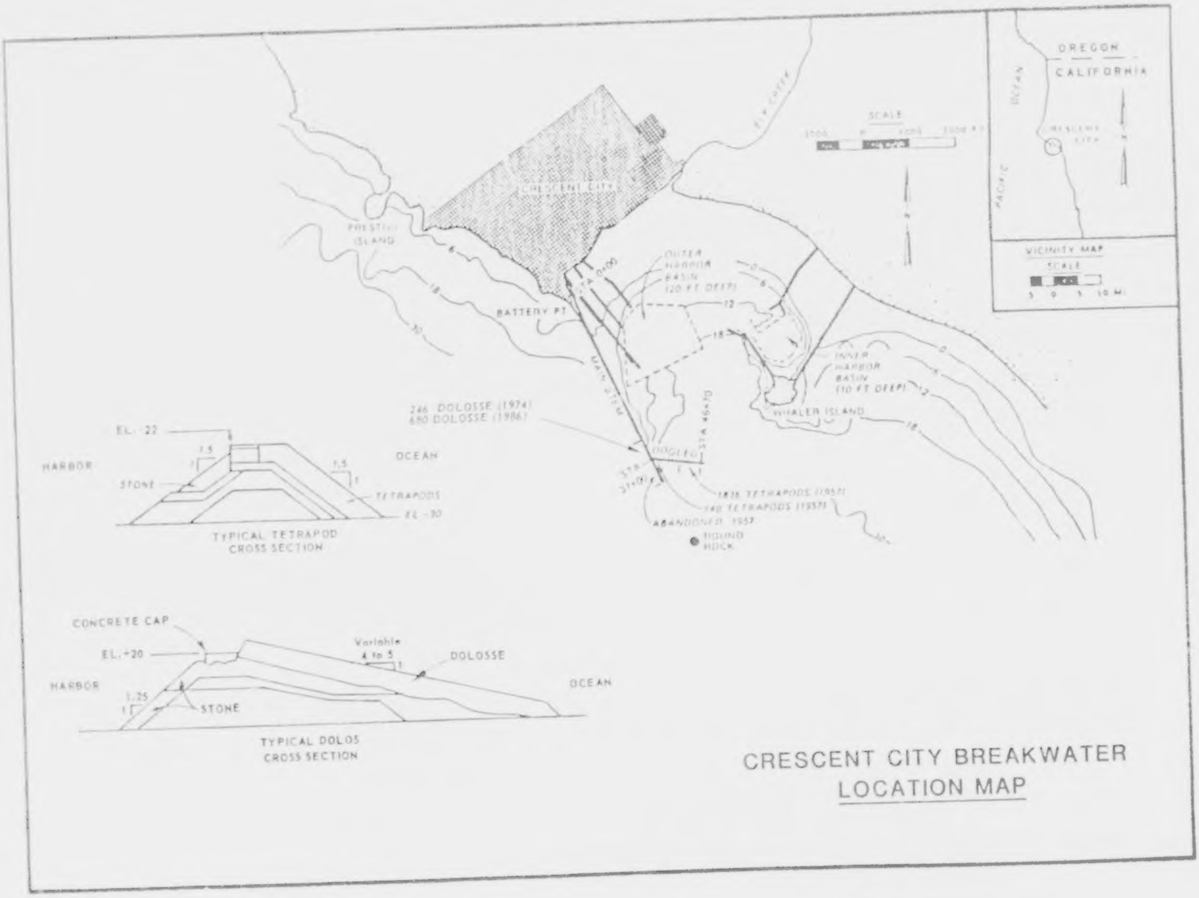

CRESCENT CITY
PRESTON ISLAND
BATTERY PT
STA 0+00
MAIN STEM
OUTER HARBOR BASIN (20 FT DEEP)
INNER HARBOR BASIN (10 FT DEEP)
WHALER ISLAND
DOGLEG
STA 46+70
STA 37+00
246 DOLOSSE (1974)
680 DOLOSSE (1986)
1836 TETRAPODS (1957)
140 TETRAPODS (1957)
ABANDONED 1957
ROUND ROCK
ELK CREEK
SCALE
OREGON
CALIFORNIA
OCEAN
PACIFIC
CRESCENT CITY
VICINITY MAP
SCALE
5 0 5 10 MI
EL. +22
HARBOR
OCEAN
1.5
1
STONE
TETRAPODS
EL. -30
TYPICAL TETRAPOD CROSS SECTION
CONCRETE CAP
EL. +20
Variable 4 to 5
DOLOSSE
1.25
STONE
TYPICAL DOLOS CROSS SECTION
CRESCENT CITY BREAKWATER LOCATION MAP

FIGURE 1 - CRESCENT CITY OUTER BREAKWATER LOCATION MAP.

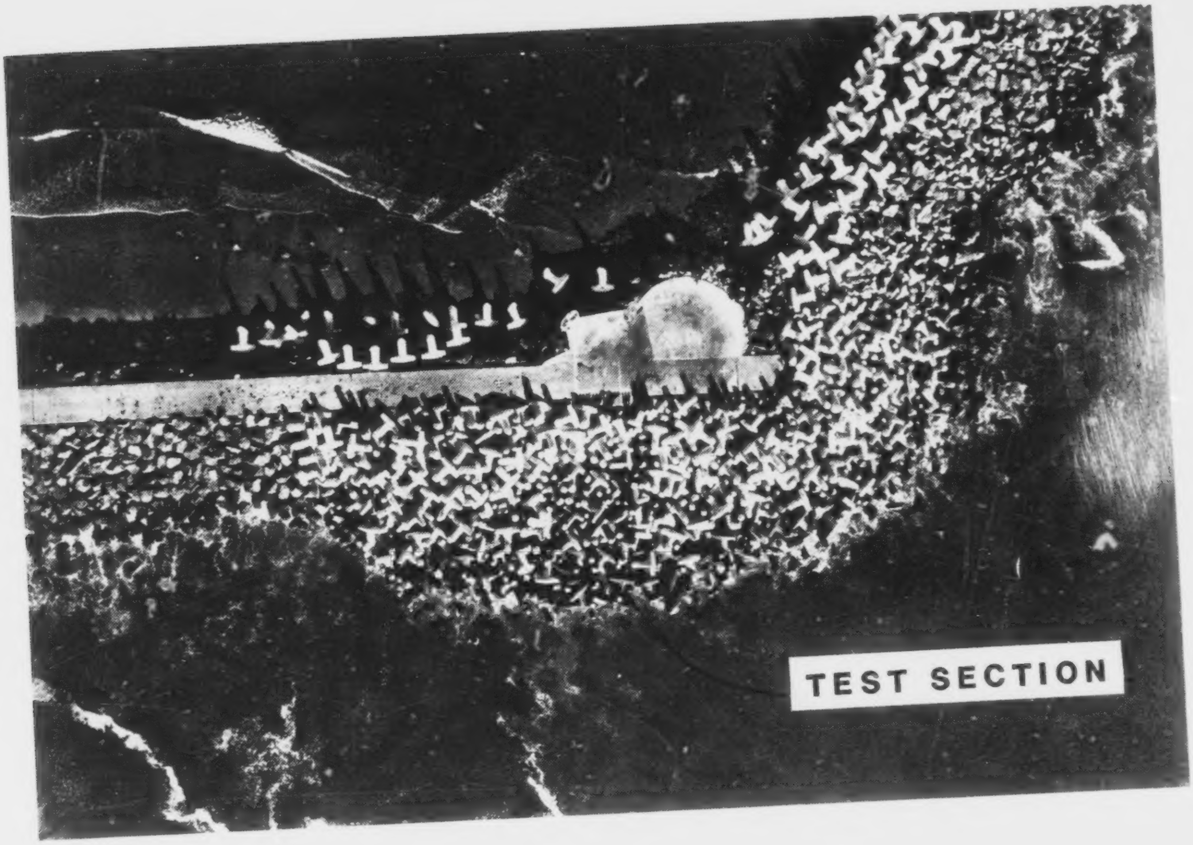


FIGURE 2- REHABILITATED CRESCENT CITY OUTER BREAKWATER AND TEST SECTION.

rehabilitation of the section occured in 1986. The rehabilitation consisted of placing 680 42-ton fiber-reinforced dolosse in the same general section, including twenty specially instrumented dolosse. Figure 2 shows the rehabilitated breakwater and the instrumented dolosse which were grouped together in one test section and given a unique color (red). This test section is the primary area where precise monitoring of dolos motions is being conducted, however, additional monitoring is also being carried out in the surrounding dolos section.

MONITORING OBJECTIVES

One of the primary objectives of collecting field data on dolos motions is to validate the use of physical models (Figure 3) to predict such motions in the laboratory. To this end, initial surveys conducted in November 1986 collected extensive data on the breakwater contours and surrounding bathymetry (2-foot contouring) for use in subsequent physical modeling of the Crescent City Outer Breakwater dolos section. Continued bathymetric and side scan sonar underwater surveys are part of the overall structure monitoring proposed.

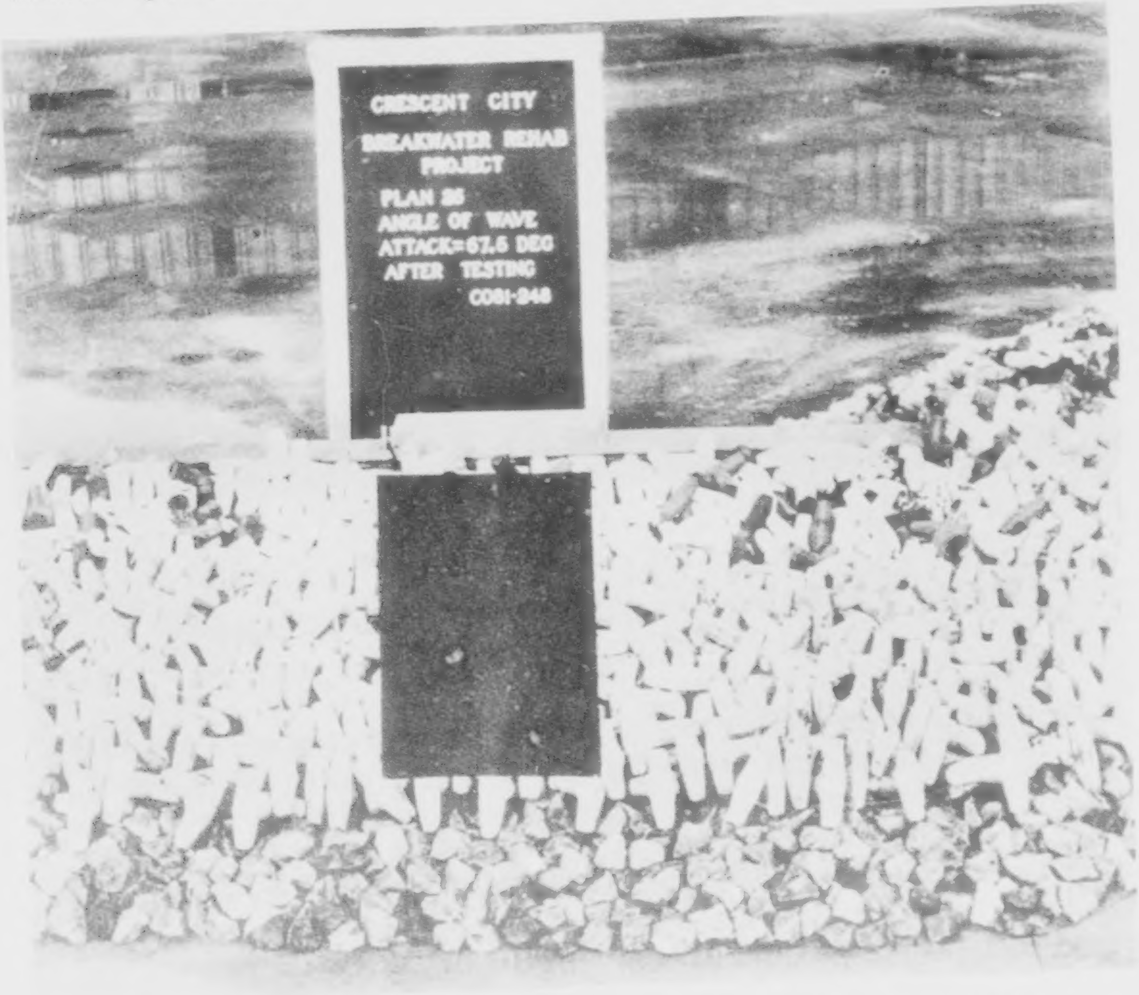

CRESCENT CITY
BREAKWATER REHAB
PROJECT
PLAN 25
ANGLE OF WAVE
ATTACK=67.6 DEG
AFTER TESTING
CO81-248

FIGURE 3- HYDRAULIC MODEL OF CRESCENT CITY OUTER BREAKWATER. The test section is designated by the retangular patch shown near the center of the photograph.

A second objective of monitoring dolos motions (and breakage) is to use these data along with the strain data and data from other elements of the overall prototype measurement program at Crescent City in an effort to validate physical modeling of forces in dolos armor units. Dolos movement data is particularly needed when modeling impact loads since while impact loads themselves may not physically scale, displacements can be scaled to determine the resulting impact loads.

The final objective of monitoring dolos motions is to provide a sequence of dolos orientation images which should prove useful in establishing orientations and boundary conditions for numerical (finite element) modeling of dolosse. Present numerical modeling efforts will use an initial field survey of dolos contact points for establishing boundary conditions, however, future plans may include modeling over the time domain in which case changing dolos orientations and approximate contact points could be inferred from the series of aerial photographs presently being collected.

The procedures tested with the Crescent City data are intended to be applied eventully to physical models of other dolos support conditions or breakwater design characteristics ultimately leading to a general design procedure for the structural strength requirements of dolos armor units.

SYNOPSIS OF MONITORING APPROACH

For precise measurement of dolosse motion, targets (typically three per dolos) were established on 26 dolosse (18 in the instrumented test section and eight distributed uniformly throughout the remainder of the dolos field). Movements have been monitored approximately monthly since late November 1986 and will continue to be monitored at least through the first two years of the repair section's life. Low altitude, high resolution photogrammetry (Figure 4) is the primary surveying technique used; land based surveys are used for periodic checks of the photogrammetric results. All target positions are surveyed vertically and horizontally with accuracies of better than 0.1 foot and recorded in a database. Cumulative movements are determined and time-series graphics are generated for any dolos experiencing a cumulative movement exceeding any multiple of 0.5 foot. In addition, rectified aerial photography of the entire dolos field is printed on mylar for overlaying each month to detect any movement of non-targeted dolos.

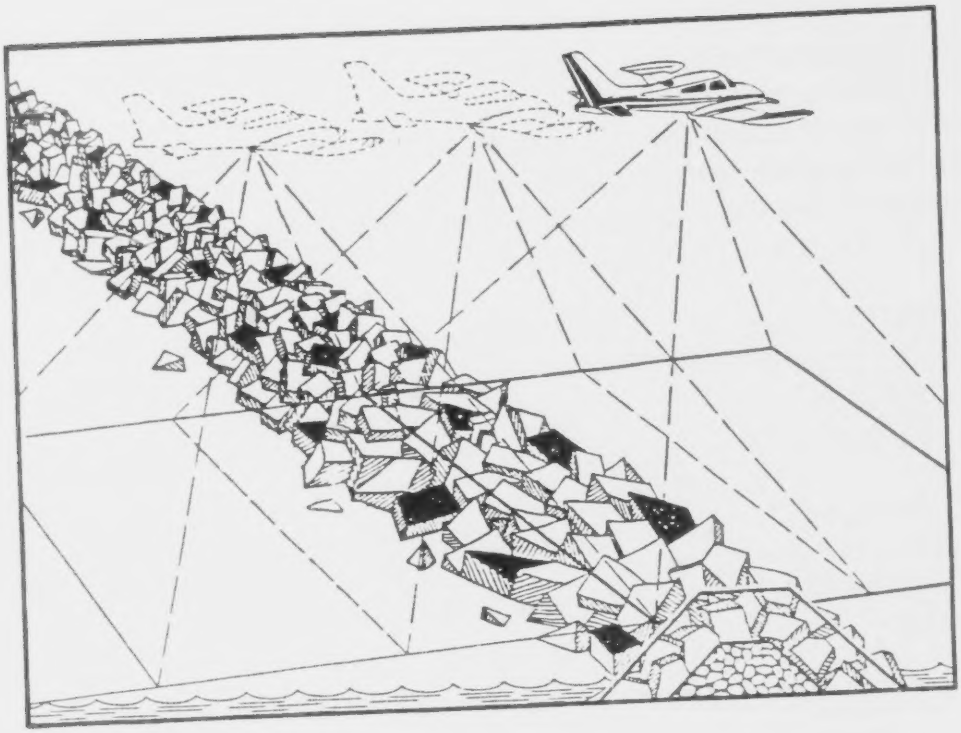


FIGURE 4- PHOTOGRAMMETRIC MONITORING OF A COASTAL STRUCTURE. (from U.S. Army Engineer Waterways Experiment Station, 1984)

ELEMENTS OF THE PHOTGRAMMETRIC MONITORING PROCESS

Photogrammetry, which is defined as the science of making reliable measurements from photographs, offers an accurate and economical means of monitoring the positions of objects visable in aerial photography. Repeated photogrammetric monitoring of the items of interest over various time intervals can result in a chronicle of movement of those items.

Of critical importance to any photogrammetric monitoring program is the proper positioning and accurate surveying of the ground control targets which are used as the basis of scaling, levelling and coordinates of the photogrammetric stereomodels. Additionally, targets must be clearly marked and identified on the objects to be monitored, in this case the 42 ton dolos.

Twenty-six (26) dolosse have been marked in this monitoring project. Twenty-two (22) of these have been marked with three targets each, while the remaining four which are located in a lower dolos layer have one target each. Targets have been painted on the dolos surface with special anti-fouling paint to discourage marine growth from diminishing the target visibility. Each target is in the form of a cross, with legs approximately 3 inches in width by 18 inches in overall length(Figure 5). Each cross is also identified with its appropriate designation (e.g. A-1, A-2, etc.) which is visible in the photography, thereby providing positive identification as to which point is being measured.

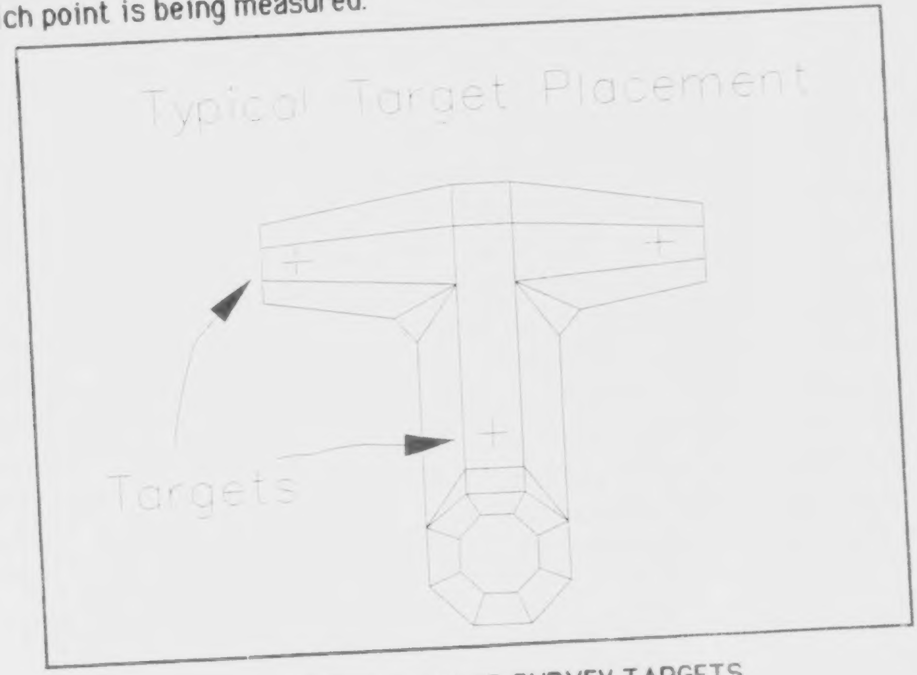


FIGURE 5- DOLOS SURVEY TARGETS.

Photography was initially taken with a 12 inch-focal length mapping camera from an altitude of 1200 feet above sea level, resulting in a photo scale of 1:1200, or 1 inch equals 100 feet. However, in order to provide more accuracy in the vertical dimension, a Wild 6-inch focal length precision mapping camera is now being used to take photography from an altitude of 600 feet above sea level, resulting in the same direct photo scale of 1:1200. Black and white aerial film (Kodak Double-X Aerographic film *2405) is used.

A Cessna Tu-206 photo plane is the platform from which the aerial photography is taken. Two photographs, taken approximately 360 feet apart in a straight line pass which bisects the angle formed by the elbow of the breakwater, form the photogrametric stereomodel from which the dolos measurements are made. Additional photo passes are made, one to the left and one to the right of the designed flight line to offer additional stereomodels to choose from if shadows or overhanging dolos prevent 3-D viewing of any target.

A Qasco fully analytical (computer driven) stereoplotter is currently being used to form the stereomodels and make the individual measurements. Initially, the photogrammetrist views the entire dolos field in sharp three-dimensional imagery at a scale of approximately 1:180, or 1" = 15'. After placing his measuring mark in the center of each survey control target, the analytical features of the stereoplotter are engaged to scale and level the stereomodel. All subsquent pointings on the dolos targets then result in their true X-Y-Z positions appearing directly on the video display. Simultaneously, each set of tri-ordinates is being recorded in a data file which is entered into a database and compared with previous measurements to detect position changes. For dolos which have remained intact, results are best interpreted by converting target movements to dolos centroid translations along and dolos rotations about each axis of the state plane coordinate system. Some example results are shown in Table 1. From these data, computer generated three-dimensional drawings are used to further illustrate dolos movements (Figure 6).

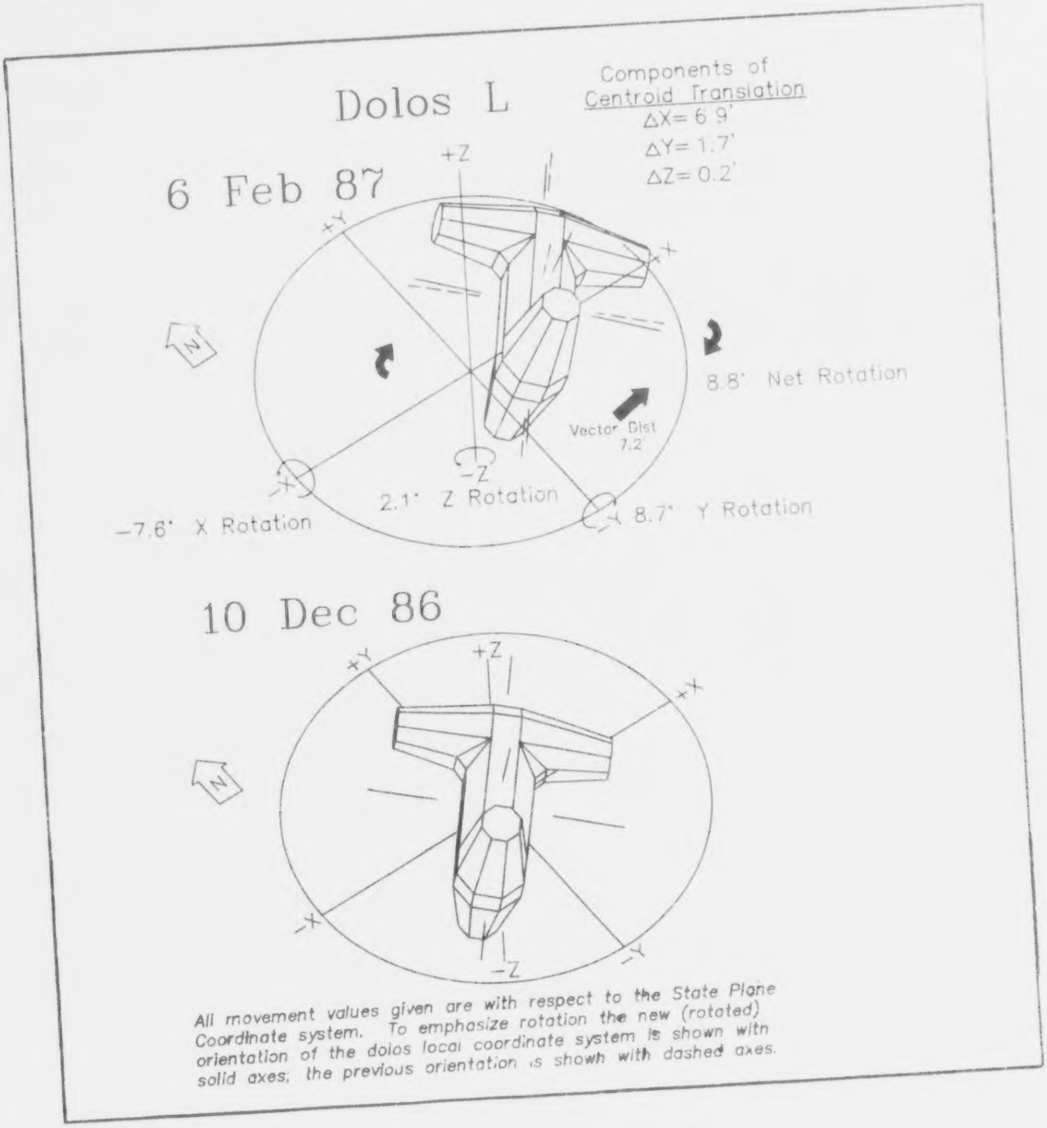
TABLE 1-

CRESCENT CITY OUTER BREAKWATER
DOLOSSE MOVEMENTS

AERIAL SURVEY ON DEC. 10, 1986
VS. AERIAL SURVEY ON FEB. 6. 1987

DOLOSSE	ROTATION ABOUT Y	ROTATION ABOUT X	ROTATION ABOUT Z	ROTATION NET	CHANGE IN Y	CHANGE IN X	CHANGE IN Z	VECTOR MAGNITUDE
A	3.06	3.61	-20.20	20.42	1.84	2.46	-0.72	3.16
B	-3.85	8.64	16.90	17.24	-0.50	1.86	-0.38	1.96
C	5.01	8.72	-5.75	7.60	0.94	0.95	-0.24	1.36
E	4.81	-5.70	2.38	5.35	-0.34	0.40	-0.23	0.60
G	-0.06	2.26	-4.04	4.40	-0.31	0.37	-0.33	0.58
L	8.66	-7.57	2.06	8.82	1.70	6.94	0.17	7.15
4	4.21	4.09	7.86	8.91	-0.96	-0.31	-0.94	1.38
6	-5.27	-3.43	-34.50	34.85	0.39	3.75	-0.15	3.77

In addition, the gross movement of targeted as well as non-targeted dolos is monitored through overlaying rectified and scaled photographic mylars which are produced at a scale of 1" = 10'. Figure 7 is an example of dolos outlines overlayed onto a photograph to illustrate the movements occurring between surveys (note the rather significant displacements experienced by dolosse L, B, and A).


Dolos L
Components of Centroid Translation
ΔX= 6.9'
ΔY= 1.7'
ΔZ= 0.2'
6 Feb 87
+Z
+Y
+X
N
8.8° Net Rotation
Vector Dist 7.2'
-Z
-X
-Y
2.1° Z Rotation
-7.6° X Rotation
8.7° Y Rotation
10 Dec 86
+Z
+Y
+X
N
-X
-Y
-Z

All movement values given are with respect to the State Plane Coordinate system. To emphasize rotation the new (rotated) orientation of the dolos local coordinate system is shown with solid axes; the previous orientation is shown with dashed axes.

FIGURE 6- THREE DIMENSIONAL DIAGRAM SHOWING MOVEMENT OF DOLOS L.

Periodic ground inspection and repainting of control survey and dolos targets is a requisite for a successful photogrammetric monitoring project, as is periodic ground surveying to compare the accuracy of the two methods.

Comparisons to date between tri-ordinates generated from simultaneous ground and photogrammetric surveys of 70 dolos targets show agreements between the two methods of approximately 0.10 foot in X-Y-Z.

Properly executed photogrammetric techniques offer a reliable, safe, accurate, economic and repeatable method of remotely monitoring the movement or condition of armor units on a coastal structure. As a bonus, aerial photographs offer a permanent archive of high resolution images which no amount of ground surveying will ever be able to duplicate.

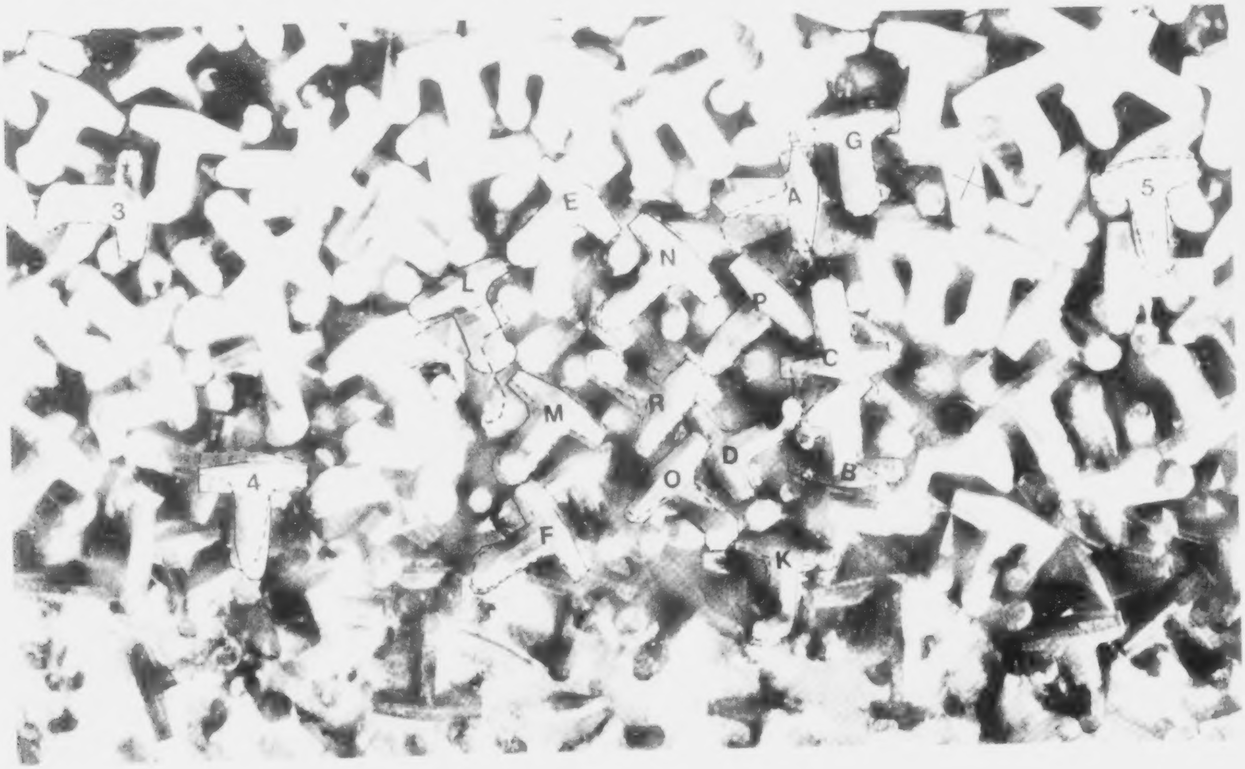


FIGURE 7- OVERLAY SHOWING DOLOSSE MOVEMENTS.
Outlines traced highlight movements between
10 Dec 1986(dashed outlines) and
6 Feb 1987(solid outlines and photo background).

DISCUSSION OF RESULTS

Of critical importance to the interpretation of the dolos motion survey results is an understanding of the wave climate driving these motions. Figure 8 shows the deepwater wave power encounterd over the first season of monitoring as well as the timing of each survey (both aerial and land--based). The figure shows deepwater wave power based on the Point St. George Buoy located approximately seven miles offshore of Crescent City as well as from the nearest continuously operating buoy located near Point Arena approximately 150 miles to the south. While other wave gages and buoys are set up nearer to the breakwater as part of the overall experiment, these only operated intermittently during the first season.

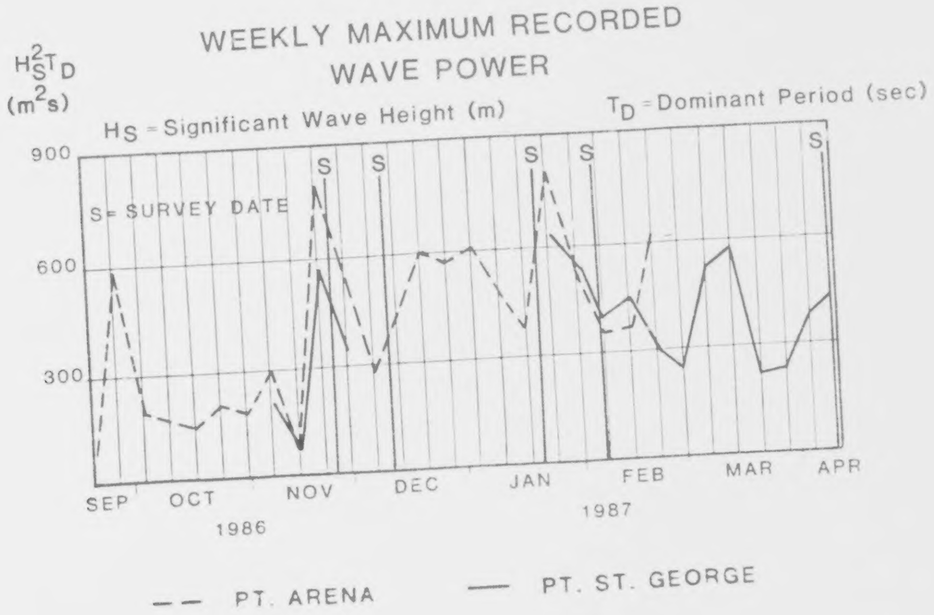


FIGURE 8- TIMING OF DOLOS SURVEYS RELATIVE TO DEEPWATER WAVE POWER.

Long period (up to 20 seconds) deepwater waves with significant wave heights on the order of 20 feet (6 meters) occurred at least four times offshore of Crescent City during the first season. Uncertainty is introduced here because of data gaps in the Point St. George Buoy record. Examining records from the Point Arena Buoy and the Navy Global Spectral Ocean Wave Model (GSOWM), suggests that a total of potentially six or seven deepwater wave events of this magnitude could have occurred offshore of Crescent City. Depending on the incident wave direction, wave period, and water level, the resulting significant wave heights near the breakwater, for these events range from 13 to 24 feet (applying refraction/diffraction/shoaling coefficients determined by Hales (1985)). Swell directions were such that the high end of this range was probably only reached once(in late December); most swell directions were from between 260^0 and 300^0 azimuth and would have resulted in significant wave heights under 18 feet.

A significant wave height of 24 feet at the structure is about 70 percent of the 35-foot depth-limited design wave for the site. While this estimated event does not represent the design storm, if a narrow wave spectrum is assumed, statistically it is expected that between 3 and 5 percent of the individual waves within this 24-foot significant wave height spectrum would exceed 35 feet. Since water depths at the structure cannot sustain wave heights in excess of 35 feet, the actual maximum wave heights potentially encountered would be limited to this design height.

Therefore, while the majority of peak events shown in Figure 8 represent wave heights below the design level, there is a strong possibility that at least one of these events may have had a small percentage of extreme wave heights associated with it which approached the design limit. Such wave events are not atypical for the breakwater dolos section and the 1986-87 storm season is simply viewed as "moderate".

The dolos motion survey results from this relatively moderate 1986-87 storm season demonstrated that this hydraulically "stable" breakwater cross-section is quite dynamic. Individual dolos units moved as much as seven feet without breaking (note dolos L in Figures 6 & 7 and in Table 1) while other units (whose failure mechanism is as yet unclear) appeared more "pinned in" and less able to move but were eventually loaded to the point of breaking. Most dolosse moved less than 0.5 feet. The most common translations experienced were towards the breakwater cap with slight settling. The greatest rotations measured (up to 34^0) were about the vertical axis (yaw).

Initially, a potential correlation was apparent between times of high wave energy (especially when wave periods were long) and times of high dolos movement. The first survey indicated on Figure 6 was conducted in late November immediately following the first post-construction storm and at the beginning of a period of relative lull in wave power. While this survey was conducted prior to establishing targets on the dolosse, the rectified aerial photography produced from it was used in an overlay process with December's photography to indicate negligible dolos motion between the two survey dates. Following the December surveys (aerial and land-based), a consistant period of relatively powerful storms occurred making it difficult to resurvey until late January (a land survey). This December/January storm period produced most all of the dolos movements recorded through the first season. Subsequent surveys in February (aerial) and April (aerial and land-based) were both preceded by relatively significant storm events yet showed no substantial increment of dolos movement beyond that recorded in January. The earlier December/January storms may have brought dolosse that were initially fairly mobile into an equilibrium (i.e. the dolosse nested and are now more stable).

Preliminary results from the surveys of September 1987 (both aerial and land-based) indicate that dolos motions over the milder summer season were almost negligible. Continued monitoring through the upcoming storm season will further test the hypothesis that the dolosse have nested and become more stable.

CONCLUSION

Photogrammetry has been found to be an extremely useful technique for monitoring the movement of dolos armor units on the Outer Breakwater at Crescent City. Comparisons with simultaneously collected land-based survey data have shown agreements between the two methods of approximately 0.10 feet in X-Y-Z. Based on this excellent agreement, fewer simultaneous ground surveys will be required during the next year of photogrammetric monitoring (proposed to continue approximately monthly through early 1989).

Unlike ground surveying, photogrammetric surveying is a truly remote form of monitoring which can be conducted safely independent of the wave climate at the coastal structure. While photogrammetry was found to be generally more expensive than ground surveying, the photographs produced in the process serve as a permanent archive of high resolution images containing much additional information. This photography has provided excellent visual documentaiton of dolos movment and breakage, even amoung non-targeted dolosse.

The results obtained thus far are being contributed to the larger pool of data on dolos behavior being collected at Crescent City. This data set along with apppropriate modeling tools should allow the Corps to progress towards a structural design methodology for dolosse.

ACKNOWLEDGEMENTS

The work described in this paper was conducted as part of the Crescent City Prototype Dolosse Study sponsored by the San Francisco District U.S. Army Corps of Engineers. The authors would like to acknowledge the support of the studys principal investigator Gary Howell of the Coastal Engineering Research Center, U.S. Army Corps of Engineers Waterways Experiment Station. The authors also wish to express appreciation to Ken Meme of Towill Inc. for his work compiling much of the intial survey results, to David Gilhousen of the National Data Buoy Center for providing the National Oceanic and Atmospheric Administration environmental buoy records, and to Jeff Gebert of the Philadelphia District U.S. Army Corps of Engineers for sharing from his experiences with photogrammetric monitoring of the Manasquan Inlet jetties in New Jersey.

REFERENCES

DOMURAT, G. W. AND G. L. HOWELL. 1984. "Measurements of Forces in Dolos Armour Units," Proceedings of the 41st Meeting of the Coastal Engineering Research Board, Seattle, Washingtion, Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, pp. 70-80.

HALES, L.Z. 1985. "Water Wave Refraction/Diffraction/Shoaling Investigation Crescent City, California," Miscellaneous Paper CERC-85-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

HOWELL, G.L. 1986. "A System for the Measurement of the Structural Response of Dolos Armour Units in the Prototype," The Dock and Harbour Authority. Volume 67, No. 779, Foxlow Publications Ltd, London, May 1986, pp. 6-10.

KENDALL, T. R., G. L. HOWELL, and T.A. DENES. "Prototype Measurment of the Structural Response of Dolos Armor Units," Proceedings: West Coast Regional Coastal Design Conference, Oakland, California, Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, pp. 288-299.

U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION. 1984. "Monitoring Rubble-Mound Coastal Structures with Photogrammetry," Coastal Engineering Technical Note CETN-III-21, Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

WOOD, W. L., G. L. HOWELL, and R. A. COLE. 1985. "Crescent City Dolos Project," Proceedings of the 43rd Meeting of the Coastal Engineering Research Board, Vicksburg, MS, Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station, pp. 114-136.

SESSION IV

AN ELEVATION STRATIFIED LAND COVER EVALUATION IN THE DEVILS LAKE BASIN, NORTH DAKOTA

R. A. Melloh
U.S. Army Cold Regions Research And Engineering Laboratory
Hanover, NH 03755

R. A. Anfang
U.S. Army Corps of Engineers
St. Paul, MN 55101

N. T. LaPotin
U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, NH 03755

ABSTRACT

An application of remote sensing technology in providing landcover information for the St. Paul District, Corps of Engineers, Feasibility Report and Environmental Impact Statement for the Devils Lake Basin, North Dakota, is presented. The objective of this study was to determine the acreage of landcover types that would be subject to inundation or construction activity under a number of alternative plans for storing or diverting excess water to alleviate high water conditions on the Devils Lake chain. An unsupervised clustering and a maximum likelihood classification algorithm were used to develop landcover maps. Overlays of diversion routes and 5-foot contour intervals were digitized from 1:24,000 topographic maps in registration with the digital imagery. The number of acres within each elevation and diversion route overlay were calculated for agricultural, grassland, deep water wetland, shallow water wetland, wetland and woodland land cover groups. A quantitative accuracy assessment of the landcover classification is presented.

INTRODUCTION

This was a cooperative study between the Cold Regions Research and Engineering Laboratory and the St. Paul District, Corps of Engineers, and was initiated and funded through the Corps Remote Sensing Demonstration Program. This study demonstrates the application of remotely sensed data and data handling techniques in providing landcover information for a Feasibility Report and Environmental Impact Statement for the Devils Lake Basin, North Dakota. The landcover classifications were needed to aid both economic and environmental evaluations.

St. Paul District's study of the Devils Lake Basin considers alternatives for alleviation of long term high water levels on Devils Lake. The Devils Lake basin is a closed drainage basin of nearly 3900 square miles in northeastern North Dakota. The water level of Devils Lake has fluctuated over the years primarily in response to climatic variations that affect the balance of annual runoff and evaporation. The level of Devils Lake, currently at about 1427 feet, has varied from 1441 feet in 1830 to 1401 feet in 1940 (Wiche et al, 1986). The recent upward trend in lake levels is a cause for concern because of the millions of dollars in flood damages that would occur if the lake level continues to rise (USACE, 1984).

One objective of this study was to determine the acreage of landcover types that would be inundated by the storage of excess runoff in natural lakes and surrounding lowlands in the Lake Irvine-Alice, Dry Lake, and Morrison-Sweetwater Lake areas north of Devils Lake (Figure 1). An additional objective was to determine the acreage of landcover directly affected by several alternatives that would route excess water from the Devils Lake basin, south to the Sheyenne River.

The study approach was to use Landsat Thematic Mapper multispectral imagery and digital image classification techniques to quantitatively assess the landcover along the proposed diversion routes and for a range of inundation levels for each of the lake storage alternatives.

STUDY AREA DESCRIPTION

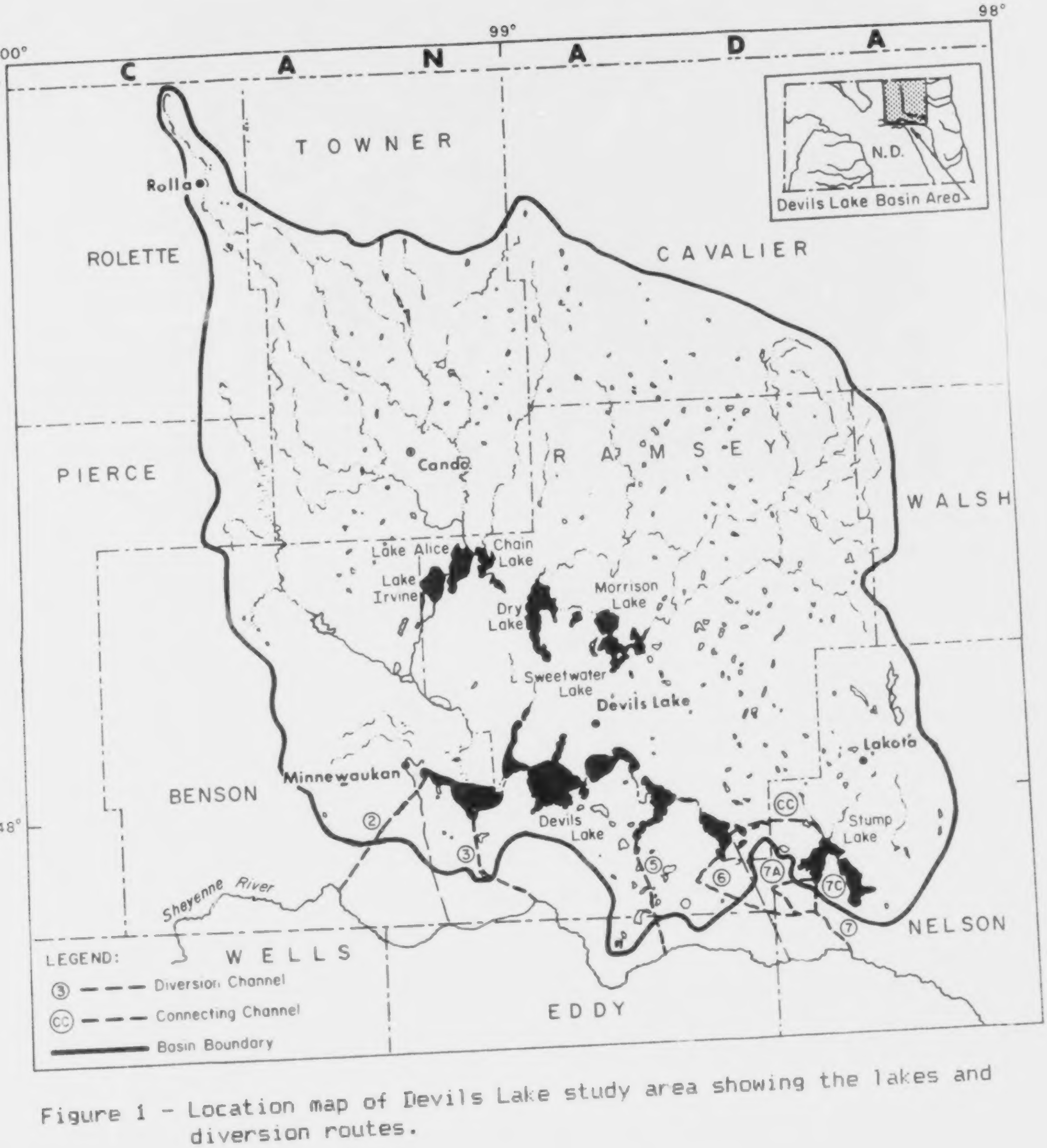
The topography of the study area is glacial in origin, varying from nearly flat to a gently rolling plain with occasional hills formed of morainal deposits. The land use is predominantly cultivated agricultural with large areas of open water, haylands and grazing lands, and a minor amount of woodlands. Wetlands other than the large ponds and lakes consist of small kettle lakes and shallow depressions called prairie potholes that dot both the cultivated and uncultivated lands.

The agricultural lands are easy to distinquish on the imagery as rectangularly shaped fields of various image tones corresponding to various crop types (Figure 2). Though no attempt was made to identify spectral signatures of individual crops, the types include wheat, barley, corn, sunflowers, oats, rye, and flax. Alteration of shallow wetlands on the agricultural land is significant during the growing season due to draining, planting, and tilling.

Grasslands include natural grasses following drainage paths, surrounding ponds and lakes, tame grasslands including brome and alfalfa mixtures in haylands, rectangular fields associated with farmsteads, and rights-of-way along major roads and highways. Wetlands may occur within depressions in grasslands. The ability to distinquish wetlands within grasslands on the imagery depends on the contrast in vegetation type or vigor and the duration and degree of soil saturation or standing water. Seasonal and temporary wetlands that may be apparent on imagery taken after spring snowmelt and heavy rains will be less apparent or absent on imagery taken during dry periods in late summer or early fall.

Woodlands are very sparse in the study area and for the most part consist of windbreaks and shelterbelts associated with farmsteads or in narrow rows between fields. A large stand of trees occurs in a hilly area near Morrison and Sweetwater Lakes, though most of the stand is at elevations above the proposed inundation levels.

Landuse maps prepared by the Bureau of Reclamation (1978) using July 21, 1976 (1:12,000 scale) color-infrared aerial photographs were available for an area that overlapped with a portion of the diversion



100°
99°
98°
49°
48°
C A N A D A
TOWNER
ROLETTE
CAVALIER
PIERCE
RAMSEY
WALSH
BENSON
WELLS
EDDY
NELSON
Rolla
Cando
Lake Alice
Chain Lake
Lake Irvine
Dry Lake
Morrison Lake
Sweetwater Lake
Devils Lake
Minnewaukan
Devils Lake
Lakota
Stump Lake
Sheyenne River
②
③
⑤
⑥
7A
7C
⑦
CC
N.D.
Devils Lake Basin Area
LEGEND:
③ — — — Diversion Channel
CC — — — Connecting Channel
Basin Boundary

Figure 1 - Location map of Devils Lake study area showing the lakes and diversion routes.

route alternatives. The wetlands were delineated according to Circular 39 of the U.S. Fish and Wildlife Service. The Bureau of Reclamation's description of the wetland classification system, as applied to the their study area, provides a description that is valid for the present study area, as well.

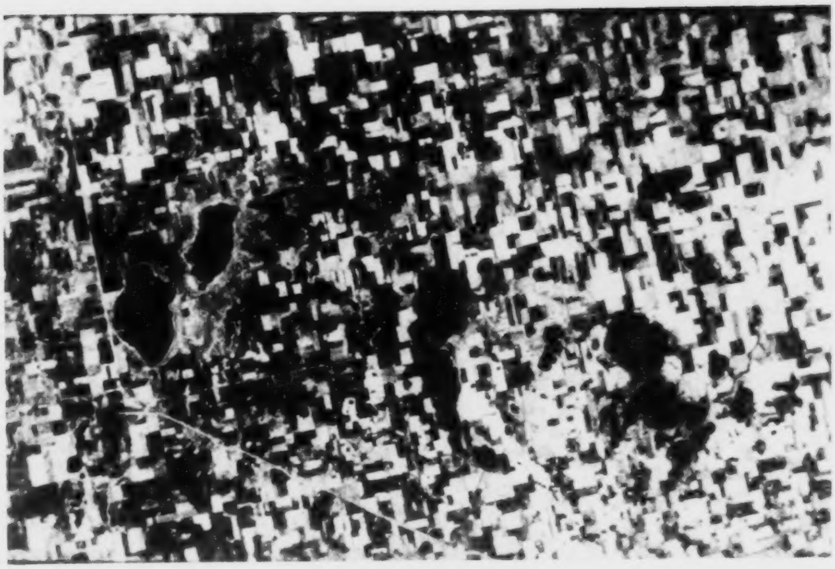


Figure 2 - September 28, 1984 Thematic Mapper subimage showing rectangular crop fields surrounding the lakes.

Type 1 wetlands are seasonally flooded basins or flats that are submerged temporarily during the spring or after snowmelt or heavy rainfalls and usually develop little or no wetland vegetation. These shallow basins are identifiable from local contrast in reflectance of the crop, grass or fallow field due to increased soil moisture, and in this study area are typically less than 0.5 acres in size.

Type 2, inland fresh meadows, are usually without standing water through most of the growing season but the soil is waterlogged within a few inches of its surface. In the study area, the fresh meadows are associated with wide coulee systems, broad shallow basins and borders of other wetlands. Coulee systems occuring in this area are small streams in steep-sided, oversized channels remnant of previous flow regimes. The vegetation types include sedges, grasses, rushes, foxtail barley and asters.

In Type 3, inland shallow fresh marshes, soils are usually waterlogged during the growing season and may be covered by 6 inches or more of water. In the study area these occur as basins within croplands and grasslands or on borders of deep marshes or lakes and are commonly 0.25 to 2 acres in size. Vegetation types include grasses, sedges, smartweed, rushes, biennial wormwood, various annuals and, less frequently, cattails. Though often tilled and planted, these wetlands usually interfere with the growth of crops.

Type 4, inland deep fresh marshes, are covered with 6 inches to 3 feet or more of water during the growing season and may nearly fill shallow basins and potholes or border open water in larger ponds and lakes. In the study area emergents such as cattails and hardstem bulrush are characteristic of deep fresh marshes and appear as dense patches or consolidated or diffuse stands. Floating aquatics and near surface submergents may also appear in open water areas.

Type 5, inland fresh water, includes shallow ponds usually less than 10 feet deep and often fringed by a border of emergent vegetation. This is the deepest wetland type encountered in the study area.

Also occuring in the study area are very limited areas of Type 6 and 7, shrub and wooded swamps. Inland saline flats, inland saline marshes and inland saline water, Types 9, 10 and 11, respectively, were also present. The saline wetlands may be interpreted on aerial photography by evidence of white saline or alkali flats and less vegetation development.

The Circular 39 classification scheme, as described above, is well suited for photo-interpretation of wetland types on small scale aerial photography by an analyst who is able to take into account associations, sizes, and patterns, and where interpretations are supplemented by extensive field observations. Both the range of spectral signatures within wetland types, and similarities between differing wetland and other landcover types, complicate the separability of the Type 1 - 4 classes using digital processing techniques that rely on spectral signatures alone. As an example, mapping of Type 3 and 4 wetlands would include the open water portions as well as the bordering vegetation, and would be distinquished as Type 3 or 4 by the percentage of open water. Additionally, the resolution of satellite imagery compared to aerial photography restricts the level of detail in interpretation, particularly for smaller features. The landcover classification for this study, therefore, does not rigorously follow the Circular 39 classification scheme.

SEASONAL INTERPRETATION KEYS

A review of remote sensing techniques applied to prairie pothole wetlands was contained in a publication titled, "Handbook of Remote Sensing in Fish and Wildlife Management" (Best, 1982). The handbook, which dealt primarily with photo-interpretation techniques on aerial photography, indicated that optimum conditions for identifying Type 1 wetlands in fields of growing grain occur in spring when the basins are full of water and are unobscured by the masking effect of growing grain. It was mentioned that Type 1 wetland delineations might also be possible after the harvest because of the continued growth of wetland vegetation during the dryer periods of the year. Type 3 wetlands could be interpreted on early spring imagery due to the seasonal presence of open water and associated marsh vegetation.

Winter scenes of Landsat-MSS imagery were found to be useful in visual interpretation of small, emergent-filled potholes that could not be mapped on spring and summer scenes (Best et al., 1974). The emergent vegetation could be identified because it was not covered with snow and had a lower reflectance than the surrounding snow-covered landscape.

In a similar study of Lac qui Parle, Minnesota, Merry et al. (1984) interpretated a simulated SPOT HRV multispectral image (20-meters resolution) taken on July 6, 1983, to determine the usefulness of the data in mapping wildlife habitat. The results of the study indicated that Type 1-2 and 3-4 wetlands were visually distinquishable on the false color composite of the summer image but that digital classification was more tenuous. Water was easily mapped digitally. Type 1-2 wetlands were not separable from classifications of the surrounding upland areas and Type 3-4 wetlands were confused with bare fields, pasture crops and corn. The forested areas, including small windbreaks around the farms, could be differentiated. The study concluded that multitemporal analysis using a spring and late summer image would be required to separate cropland from wetland types in the Lac qui Parle area.

IMAGE ACQUISITION AND PREPROCESSING

Early fall, cloud-free Thematic Mapper images, IDY5021116524X0 (quads 3 and 4) and IDY5021116530X0 (quads 1 and 2), acquired by Landsat-5 on September 28, 1984 were purchased from Earth Observation Satellite Company (EOSAT). The digital data were collected in seven spectral bands at a nominal resolution of 30 meters. The wavelengths and range of the seven band digital data are shown in Table 1. The digital data were radiometrically and geometrically corrected by NASA's Thematic Mapper Image Processing System (TIPS) and resampled onto a Space Oblique Mercator (SOM) map projection. TIPS resampling results in a reduced pixel size of 28.5 by 28.5 meters. Analyses show the internal geometric accuracy of TM data generated by the TIPS to be better than 15 meters root-mean-square, or about 0.5 pixel (Welch et al., 1985; Colvocoresses, 1986.).

Preparation of contiguous images across the upper lakes area required a merge along a common scanline of the north and south thematic mapper images. An east/west merge was also required to cover the easternmost diversion route alternatives. The east/west merge required joining image quads along an edge that stepped over one pixel each 22 lines. Custom software tasks were written and integrated with the ARIES-II image processing system to carry out the merges.

TABLE 1 - THEMATIC MAPPER SPECTRAL BANDS

Band	Wavelength Range (Micrometers)	
1	0.45 - 0.52	Visible (Blue)
2	0.52 - 0.60	Visible (Green)
3	0.63 - 0.69	Visible (Red)
4	0.76 - 0.90	Near Infrared
5	1.55 - 1.75	Middle Infrared
7	2.08 - 2.35	Middle Infrared
6	10.40 - 12.50	Far Infrared (Thermal)

UNSUPERVISED SIGNATURE GENERATION

An unsupervised signature generation was conducted using Dipix, ARIES-II Image Analysis System software (Letts, 1978; DIPIX, 1986). The unsupervised process requires a limited amount of operator input. The steps are described as follows:

1. The operator looks at a pixel frequency histogram for each band of data and limits the histogram range of brightness values to the actual range of the digital data. Though TM data are quantized to 8-bit resolution, the actual data range will normally be less than the maximum 256 levels.

2. The operator defines the resolution used in each feature, or band, by assigning the number of bins used to describe the feature histogram. For example, a histogram of values ranging from 10 to 120 in brightness values might be described by an 11-bin histogram with 10 pixels in each bin (Figure 3). Assigning an equal weight to each feature requires assigning an equal number of bins to each feature histogram.

3. An n-dimensional pixel frequency histogram, where "n" corresponds to the number of bands, is built and arranged in memory. The n-dimensional histogram is searched for local maxima of pixel frequency. In two dimensions, local maxima can be visualized as clusters in feature space. These clusters are merged into parallelopiped classes based on the degree of overlap of the clusters (Figure 4) and a merge factor, which is selected by the operator.

4. The parallelopiped classes are then used to classify the image data in a first pass. This first pass classification is not saved or revealed to the operator.

5. Data values corresponding to the classified pixels are then used to generate statistics for maximim likelihood class signatures.

In summary, the unsupervised clustering routine generates hypothetical training areas through automated evaluation of the multi-band data set and derives maximum likelihood signatures, with minimal operator input.

An upper lakes image of 700 x 1359 pixels was used to generate the maximum likelihood signatures as described above. All seven bands of the TM data were used. The clustering algorithm identified 46 local maxima in the 7-dimensional histogram. A merge factor that would maximize the number of classes was selected. The merge resulted in 29 maximum likelihood class signatures. The 29 signatures were used to classify both the upper lakes and diversion route images. Each of the diversion route images included a large rectangular area encompassing its respective diversion route.

CLASSIFICATION RESULTS

The classification maps were taken to the field during July 1986 to verify and label classes according to corresponding landcover types.

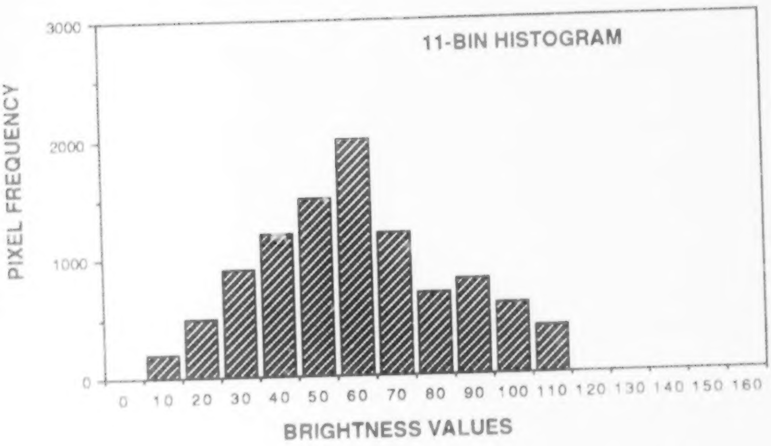


Figure 3 - 11 Bin pixel frequency histogram.

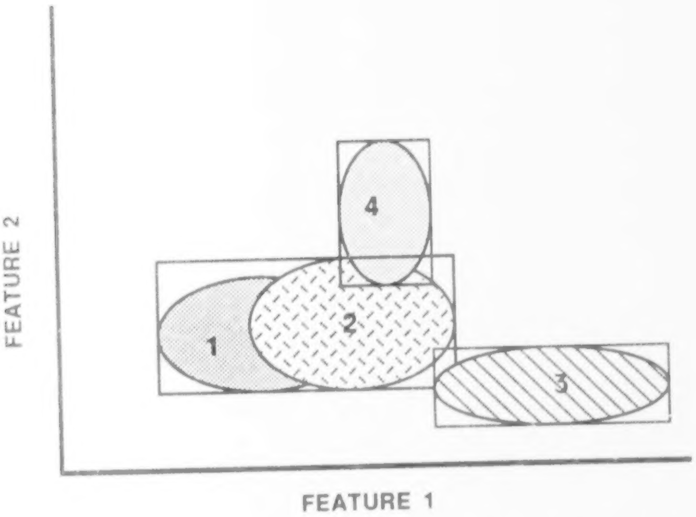


Figure 4 - Merge of clusters into parallelopiped classes.

Black and white aerial photographs taken on May 17, 1983 were used both in the field and back in the office to extend site observations and evaluate the classification results. The aerial photography was acquired jointly by the North Dakota State Water Commission and the St. Paul District, Corps of Engineers, to document high water conditions during the spring of 1983 and, therefore, represented wetter conditions than those encountered in the field or on the late September imagery.

Fourteen of the classes were identified as agricultural. The agricultural land in the late September image was in post-growth stage, exhibiting dried crops, and harvested fields. The agricultural classes were assigned mainly on the basis of rectangularly shaped fields and by exclusion of classes that obviously corresponded to another landcover type. The image tones of the agricultural fields as displayed on a color infrared false color composite (Bands 4,3,and 2 displayed as red, green and blue, respectively) ranged from white to dark gray.

Three of the classes were identified as grasslands. The grasses were found around lakes, ponds, and streams, along roads and in scattered fields. The grasses that remained green later in the year than the crop fields were separable on this late September image. The grasslands appeared as yellow and pink tones on color infrared false color composites.

Three of the classes were identified as deep water wetlands. The group included the larger open water bodies and ponds including Dry Lake, Lake Irvine and Morrison and Sweetwater Lakes. This wetland type corresponds most closely with the Type 5 wetlands described above. The open water classes were easily distinguished due to lower reflectance in infrared bands 4,5 and 7.

Six classes were assigned to shallow water wetlands. These wetlands included small open water ponds and shallow water areas bordering deep water wetlands. The reflectances in infrared bands for these shallow water classes were higher than in the deep water wetland group, which might be interpreted as an indication of floating aquatics or emergent vegetation. This group corresponds most closely to the open water portions of Type 3 and 4 wetlands. Lake Alice, a large open water body, was included in the shallow water wetland group. Lake Alice is located in a National Wildlife Refuge and its level is regulated for waterfowl management. In the fall of 1984 the level of Lake Alice was drawn down. In the image, the lake water appeared to be turbid, which could be expected for a large shallow lake where a slight wind may cause enough wave action to suspend bottom sediments.

Another wetland group was identified, consisting of two classes that corresponded to wetland vegetation and one very small class that corresponded to mudflats. These classes frequently surrounded the deep and shallow open water areas but also included wet areas in fields and larger potholes completely filled with vegetation. These wetland vegetation classes correspond most closely with Type 3 and the borders of Type 4 and 5 wetlands. This group was a consistent indicator of cattail stands; unfortunately, it also included woodlands. Cattail marshes and woodlands both appeared as bright red signatures on the color infrared false color composites and did not separate in the 7-band digital classification. Some of the larger Type 1 and Type 2 wetlands may also be included in this group due to their contrast with the dried or harvested crops in this fall image. However, confusion between Type 1-3 wetlands and grasslands was apparent. A quantitative accuracy assessment of the classification is discussed in a later section.

STRATIFICATION OF LANDCOVER USING MAP OVERLAYS

North-south aligned subimages of the three upper lake areas and seven diversion routes were created by rotating the digital images 11.9 degrees clockwise. Each image was then registered to UTM (Universal Transverse Mercator) map coordinates of U.S.G.S. 1:24,000 scale topographic maps mounted on a digitizing board. The registrations were accomplished by selecting six ground control points and calculating second-order polynomial transforms (Dipix, 1986). Overlays representing inundation levels for each of the lake areas were generated by tracing specified contour lines on the maps. Water levels of the major water bodies were also digitized from the 1951 topographic maps and were found to be higher than the water levels observed on the September 1984 satellite imagery. The lake area overlays are enumerated on Table 2. Overlays were generated for each diversion route by tracing plan drawings provided by the St. Paul District.

The digital classification maps were compared to the digital overlays and the number of pixels of each landcover group within each elevation or diversion route overlay were calculated. Woodland overlays were digitized from 1:24,000 scale topographic maps and adjustments of pixel counts were made to account for this proportionately small but important habitat class. Resulting stratified landcover classifications for the three lake areas are provided in Table 3. Table 4 provides the landcover determinations for diversion routes 2, 3, 5c, 6, 7a, and 7c. Route 7a and 7c tabulations both include acreages for route 7, shown on Figure 1. Landcover determinations for the Connecting Channel diversion route were also stratified by elevation and are given on Table 5.

ACCURACY ASSESSMENT

An accuracy assessment was made to provide a quantitative measure of reliability of the classification maps. The assessment was made by

TABLE 2 - UPPER LAKES ELEVATION OVERLAYS

		Lakes Irvine-Alice	Dry Lake	Morrison-Sweetwater Lakes
Digitized Water Level (ft)	1439.6	1447.5	1458.5	
Surface Area (sq mi)		14.2	9.6	12.0
Overlay Elevation(ft)		**Inundated Area (sq mi)**		
1445		28.3		
1450		48.3	13.9	
1455			21.2	
1460			28.4	18.9
1465				28.5

TABLE 3 - CUMULATIVE INUNDATION OF LANDCOVER BY ELEVATION
(in square miles)

a. Lake Irvine-Alice

	1450 ft	1445 ft	Digitized Water Level
Agricultural	19.5	5.5	0.4
Grassland	12.2	7.7	1.3
Deep Water.Wetland	6.4	6.4	6.4
Shallow Water Wetland	5.0	4.9	4.5
Wetland	5.0	3.7	1.6
Woodland	0.1	0.0	0.0
Unclassified	0.1	0.1	0.0
Total	48.3	28.3	14.2

b. Dry Lake

	1460 ft	1455 ft	1450 ft	Digitized Water Level
Agricultural	15.1	9.0	3.1	0.3
Grassland	2.7	2.0	1.1	0.3
Deep Water Wetland	7.7	7.7	7.7	7.7
Shallow Water Wetland	0.8	0.7	0.7	0.5
Wetland	1.7	1.5	1.2	0.7
Woodland	0.3	0.2	0.1	0.1
Unclassified	0.1	0.1	0.0	0.0
Total	28.4	21.2	13.9	9.6

c. Morrison and Sweetwater Lakes

	1465 ft	1460 ft	Digitized Water Level
Agricultural	13.0	5.5	0.6
Grassland	2.8	1.4	0.4
Deep Water Wetland	8.6	8.6	8.5
Shallow Water Wetland	2.2	2.1	1.7
Wetland	1.3	1.1	0.7
Woodland	0.5	0.1	0.1
Unclassified	0.1	0.1	0.0
Total	28.5	18.9	12.0

verifying the correctness of class assignments at randomly selected pixel locations. A sampling scheme was developed and software was written to implement the procedure on an ARIES-II Image Processing System. The procedure divides the thematic map into a 4 by 4 grid. Samples are then selected for each theme in proportion to the number of pixels within that theme in the entire image and within each of the 16 segments. This is defined as a stratified random areal sample with variable sampling proportions (Berry et al., 1968). The sampling scheme

TABLE 4 - DIVERSION ROUTE LANDCOVER (ACRES)

	Diversion Route					
Landcover Classification	2	3	5c	6	7a	7c
Agricultural	192	129	216	94	84	75
Grassland	519	421	153	352	313	109
Deep Water Wetland	44	138	34	0	0	0
Shallow Water Wetland	567	167	235	19	31	0
Wetland	167	85	80	142	33	5
Unclassified	24	26	2	4	4	0
Total	1513	966	720	611	465	189

TABLE 5 - CONNECTING CHANNEL LANDCOVER (ACRES)

	West		East	Total
	1445 ft	1450 ft		
Agricultural	255	576	49	625
Grassland	344	430	94	584
Deep Water Wetland	1	1	1	2
Shallow Water Wetland	218	223	8	231
Wetland	106	131	21	152
Unclassified	6	10	1	11
Total	930	1431	174	1605

is intended to ensure geographic coverage by the random sample and adequate sample sizes for smaller thematic classes. The procedure creates an image of sample pixels that are color coded to correspond to the original class sampled. The overlay may be displayed on top of a false color composite and flicked on and off during the verification process.

Only the Lake Irvine - Alice image was used in the accuracy assessment. Due to the similarity of the other lake and diversion route images, the assessment is assumed to approximate the accuracy of the other classification maps, as well. Verifications of 296 sample pixels were made using the May 1983, 1:30,000 scale, black and white aerial photography and recorded field observations. Methods described by Jensen (1986) were used to tabulate the classification errors. An error matrix is presented on Table 6. The diagonal line indicates correctly classified pixels. Errors of omission for each class are computed by summing the number of pixels assigned to incorrect categories along each row. Errors of commission are computed by summing the number of pixels assigned to incorrect categories along each column. The number of correctly classified pixels was 255 out of 296 for an overall 86% accuracy.

TABLE 6 - ERROR MATRIX

Actual Land Use	Interpreted Land Use 1	2	3	4	5	6	7	Total
1. Agricultural	91	12			7			110
2. Grassland	9	72						81
3. Deep Water Wetland			36					36
4. Shallow Water Wetland				28				28
5. Wetland		8			28			36
6. Woodland					2	0		2
7. Road	2	1					0	3
Total (pixels)	102	93	36	28	37	0	0	296

The individual class accuracies and 95% confidence limits were computed and are shown on Table 7. The results show that the deep water wetland and shallow water wetland classes were very accurately discriminated. Agricultural lands were sometimes misclassified as grassland and sometimes as wetland. Grasslands were sometimes misclassified as agricultural. Wetlands were sometimes misclassified as grasslands. Of the total number of wetland pixels encountered, 22% had been misclassified as grassland. This tendency to classify wetlands as grasslands was partly due to the difference in wetness that existed between the fall image and wet spring conditions evident on the May 17, 1983 aerial photographs. The photographic, "assumed true" data set, was observed to include standing water and associated temporary or seasonal wetlands which were either nonexistent or less apparent as wetlands on the TM imagery. This discrepancy was noted primarily in the grassland/wetland complex surrounding Lake Alice and Irvine.

The Bismarck Field Office of the U.S. Fish and Wildlife Service also determined habitat types and acreages along some of the diversion routes. The FWS interpreted April and August aerial photography of various dates in 1978, 1981 and 1982, and at scales of approximately 1:16,000, using a dot grid method of counting. A comparison of the dot

TABLE 7 - INDIVIDUAL CLASS ERROR EVALUATION

		Omission			Commission		
Class	Points Correct	Number Samples	% Correct	95% Confidence Limits	Number Samples	% Correct	95% Confidence Limits
Agricultural	91	110	83	75-90	102	89	83-96
Grassland	72	81	89	81-96	93	77	68-86
Deep Water Wetland	36	36	100	99-100	36	100	99-100
Shallow Water Wetland	28	28	100	98-100	28	100	98-100
Wetland	28	36	78	63-93	37	76	61-91

Overall Accuracy (255/296) = 86%

TABLE 8 -AERIAL PHOTOGRAPHY - DOT GRID METHOD COMPARISON (ACRES)

	Landsat Imagery		Aerial Photography		Difference	
Landcover	Route 2	Route 3	Route 2	Route 3	Route 2	Route 3
AGRICULTURAL	192	129	164	0	+28	+129
GRASSLAND	519	421	401	262	+118	+159
Deep water wetland	44	139				
Shallow water wetland	567	167				
Wetland	167	85				
Unclassified	24	26				
TREES	0	0	69	54	-69	-54
Wetland type 1			20	0		
type 2			120	20		
type 3			59	47		
type 4			254	248		
type 5			449	103		
Saline wetland			0	130		
TOTAL WETLANDS	778	391	902	548	-124	-157
TOTAL ACRES	1513	967	1536	864	-23	+103

grid results with this studies' results are provided on Table 8 for diversion routes 2 and 3. Though there were some differences in the total area covered, the comparison suggests that this study overestimated grasslands and underestimated wetlands, when compared to acreages determined by the Fish and Wildlife service. This is in agreement with the accuracy assessment results which indicated that wetlands were sometimes misclassified as grasslands.

SUMMARY AND RECOMMENDATIONS

This study demonstrated the use of satellite data analyses in a Corps feasibility and environmental impact study. Landcover tabulations by elevation were provided for a large study area to aid both economic and environmental evaluations of a number of alternative plans. Accuracy of the landcover maps was assessed to provide the user a measure of map reliability. Color prints and slides of the satellite-derived landcover maps were also found to be useful in conveying study concepts and findings at public meetings.

An evaluation of the accuracy of the landcover maps indicates that deep water and shallow water wetland classes were easily mapped on the fall imagery. The imagery was useful in distinquishing agricultural land from grassland and wetland vegetation, though there was some degree of confusion. Wetland vegetation was sometimes misclassified as grassland though grassland was seldom misclassified as wetland. Part of the error in distinquishing wetlands from grasslands is attributable to the difference in moisture conditions between the fall imagery and wet spring aerial photography used as the verification data set. Temporary and seasonal wetlands apparent in the spring after snowmelt or heavy rains were nonexistant or less discernable on the fall imagery. Woodlands were not separated from wetland vegetation in the digital classification.

A multitemporal analysis, which could take advantage of certain seasonal interpretation keys, would be the recommended approach to improving the accuracy of digital classifications of this study area. A fall image could be combined with a spring image to improve mapping of temporary or seasonal wetlands. A winter image, on the other hand, may improve separability of emergent vegetation from grass and crops. A seasonal analysis might also provide a method of estimating the seasonal change in the number and extent of wetlands available as wildlife habitats.

ACKNOWLEDGMENTS

We wish to acknowledge the assistance of Harlan L. McKim, Program Manager, Remote Sensing Research Program, and Carolyn J. Merry, both of CRREL, and William Spychalla and Gary Green of the St. Paul District for their contribution in the initiation of this cooperative study. Larry Viekley, Roger Hollovoet and Dave Janes of the Devils Lake Wetlands Management District of the U.S. Fish and Wildlife Service provided field assistance and helpful discussions of the landcover in the study area. Mark Dryer of the Bismark Field Office of the U.S. Fish and Wildlife Service provided habitat information for the diversion route alternatives. Lawrence Gatto and Timothy Pangburn of CRREL provided technical reviews of this report.

REFERENCES

BERRY, B.J.L.; A.M. BAKER, "Geographic Sampling"; in B.J.L. BERRY and D.F. MARBLE, editors, Spatial Analysis - A Reader in Statistical Geography, Prentice-Hall, 1968, pp. 91-100.

BEST, R.G.; D.G. MOORE; R. LINDER, "Inventory of wetlands using ERTS-1 data: Codington County, South Dakota," South Dakota State University, Remote Sensing Institute (SDSU-RSI-74-19), 1974, 23 pp.

BEST, R.G., "Handbook of Remote Sensing in Fish and Wildlife Management," South Dakota State University, Remote Sensing Institute, (SDSU-RSI-82-05) 1982, 105 pp.

BUREAU OF RECLAMATION, Bismarck, North Dakota, 1:24,000 scale Habitat Overlay Maps prepared in connection with the Garrison Diversion Project, 1978.

COLVOCORESSES, A.P., "Image Mapping with the Thematic Mapper," Photogrametric Engineering and Remote Sensing, Vo.52, No.9, 1986, pp 1499-1505.

DIPIX Systems Limited, ARIES Systems Users Manual, Version 3.2, Part 1 and 2, April 1986.

JENSEN, R.J., "Introductory Digital Image Processing, A Remote Sensing Approach," Prentice-Hall, 1986.

LETTS, P., "Unsupervised Classification In the ARIES Image Analysis System," Presented to the 5th Canadian Symposium on Remote Sensing, Victoria, Canada, August 1978, 11p.

MERRY, C.J.; GREEN, G.; ANDERSON, S., "Wildlife Habitat Mapping in Lac qui Parle, Minnesota: SPOT Simulation Applications Handbook," Proceedings of the 1984 SPOT Symposium, May 20-23, Scottsdale, Arizona, pp 205-208.

U. S. Army Corps of Engineers, St. Paul District, "Devils Lake Basin, North Dakota, Reconnaissance Report," 1984, 29 pp.

WELCH, R.; T. R. JORDAN; M. EHLERS, "Comparative Evaluations of the Geodetic Accuracy and Cartographic Potential of Landsat-4 and Landsat-5 Thematic Mapper Image Data," Photogrammetric Engineering and Remote Sensing, Vo.51, No.9, September 1985, pp. 1249-1262.

WICHE, G. T.; S. M. HOETZER; J. G. RANBL, "Hydrology of the Devils Lake Basin, Northeastern North Dakota," North Dakota State Water Commission, Water Resources Investigations Report 3", 1986.

THE RED RIVER ARCHEOLOGICAL PROJECT: THE APPLICATION OF REMOTE SENSING

W.J. Bennett, Jr.

Vice President, Archeological Assessments, Inc.
Nashville, AK

and

Lawson M. Smith

Chief, Engineering Geology Group
Geotechnical Laboratory, U.S. Army Corps of Engineers
Waterways Experiment Station, Vicksburg, MS

and

Mark Laustrup

Manager, Remote Sensing Applications Laboratory
University of Nebraska-Omaha, Omaha, NE

ABSTRACT

The Red River Valley Archeological Project is long term effort involving numerous individuals and institutions engaged in archeological studies in the Texas and Oklahoma portions of the Red River Valley. The primary focus of these investigations has been on site location. This presentation reports on the use of a variety of remotely sensed data as integrated with a geomorphological and archeological analysis of a portion of the Holocene floodplain. Particular emphasis is placed on the interpretation of data acquired in February 1985 using Thermal Infrared Multispectral Scanner (TIMS). The results of this effort are analyzed and a discussion of both theoretical and operational issues involved in the integration of TIMS and other remotely sensed data into archeological investigations is given.

WETLAND DELINEATION USING
MULTI-TEMPORAL LANDSAT THEMATIC MAPPER DATA

Ross S. Lunetta

U.S. Army Corps of Engineer, Detroit, MI

and

James G. Fricke

Department of Geography and Geology
Eastern Michigan University

and

Wendy S. Hutchinson

Department of Civil Engineering
Ohio State University

ABSTRACT

Thematic Mapper (TM) Data collected on March 25 and August 21, 1984 was analyzed to delineate freshwater palustrine wetlands in the Saginaw River Basin, Michigan. A multi-temporal analysis of TM data was performed using a two step process. First, the two TM data sets were categorized separately, then were processed using a Geographical Information System (GIS) procedure to produce a final conjugate multi-temporal product. The TM data analysis provided hydrophytic vegetation, wetland hydrology and hydric soils data to facilitate accurate wetland delineation. U.S. Department of Agriculture soils survey data and field vegetation inventory data were used to substantiate the accuracy of the vegetation and soils data extracted from TM satellite imagery.

The final multi-temporal product was compared to two land cover/vegetation data bases developed independently by the Corps of Engineers and the Michigan Department of Natural Resources using conventional, photointerpretation techniques. Comparisons indicate that conventional single data photointerpretation significantly underestimated the extent of forestland wetlands in the study area.

EVALUATIONS OF THE ST. MARYS RIVER ENVIRONMENT USING AIRBORNE MUTLISPECTRAL SCANNER DATA

John G. Lyon

U.S. Army Corps of Engineers, Detroit, MI
and Department of Civil Engineering
The Ohio State University

and

Ross S. Lunetta

and

Donald C. Williams

U.S. Army Corps Engineers District
Detroit, MI

ABSTRACT

Airborne multispectral scanner data has been employed to map riverine emergent wetlands, submerged macrophytes, bottom types, and general water depths in the St. Mary River, Michigan. Eleven channel 10-meter resolution scanner data and simultaneous 1:24,000 scale, natural color aerial photographs were collected on an overflight conducted on October 19, 1985. The scanner data were used to generate both image and computer categorization products. Emergent wetlands, bottom types and general water depth were categorized directly using channels 3,4,5, and 6 (0.45 - 0.50, 050-0,55, 0.55-0.6 and 0.6-0.65 um). Submerged macrophytes were indirectly mapped by correlating bottom types and water depths to produce a map indicating their greatest probability of occurrence.

The categorized data produced a very good product in part due to the very transparent waters of oligotrophic Lake Superior which flows through the St. Marys River. Categorization by clustering effectively separated the spectral contribution of the bottom from the spectral backscatter, forescatter, and extinction of light from the water. The presence of water effectively caused high intercorrelation of spectral signatures from water with different bottom types. Clustered classes explained much of the variability in the data and the individual contribution of bottom type to the overall volume reflectane from the water, thereby allowing measurements of depth.

Use of LANDSAT MSS Data to Estimate Drought Conditions, Precedent Flow Conditions, and Tree Growth of Bottomland Hardwoods of the Neches River Basin, Texas

Paul M. Hathorn
U.S. Army Corps of Engineers, Fort Worth District
Planning Division, Environmental Resources Branch
819 Taylor Street
Fort Worth, Texas 76102-0300

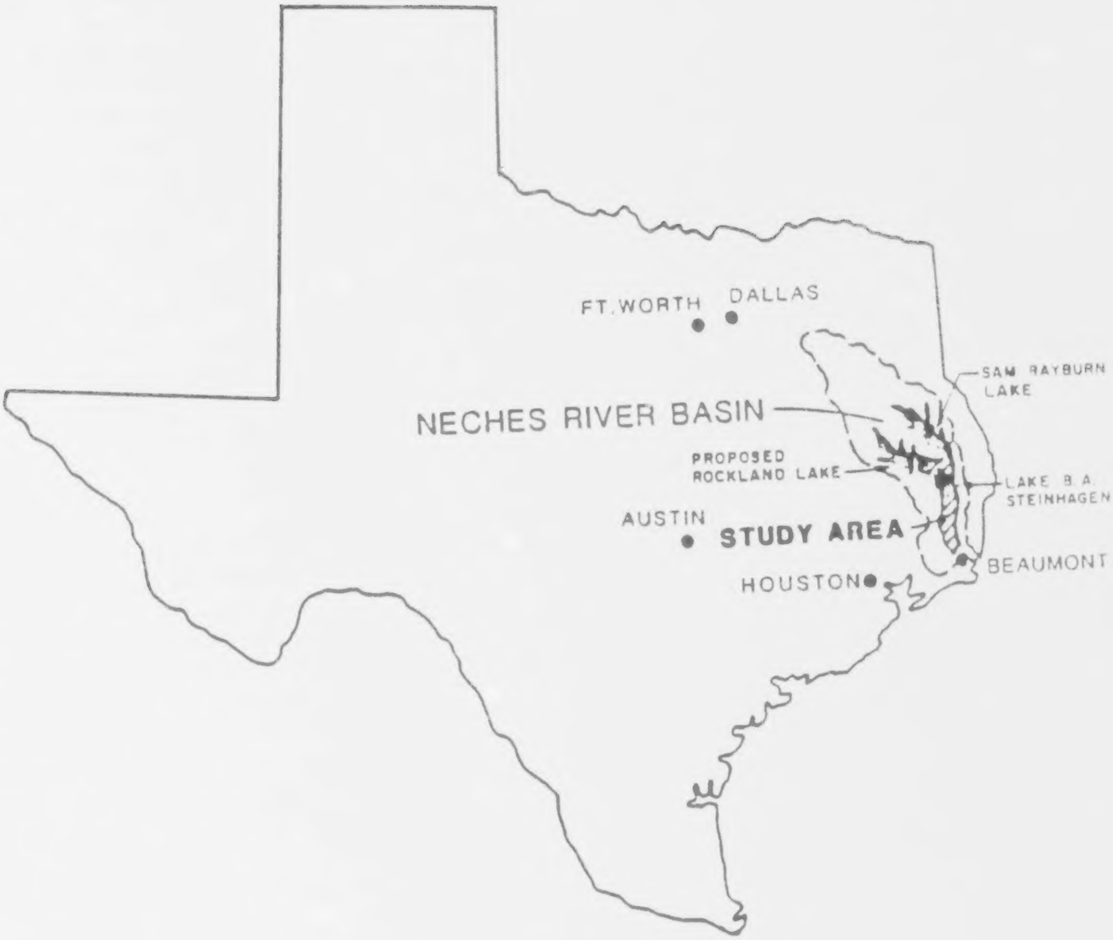
Samuel F. Atkinson, PhD.
Center for Remote Sensing and Landuse Analysis
Institute of Applied Sciences
University of North Texas
P.O. Box 13078
Denton, Texas 76203-3078

ABSTRACT

Five temporal LANDSAT MSS scenes were used to develop models which predicted Annual Drought Index, Mean River Flow (annual), Maximum River Flow (annual), and Basal Area Index of growth of bottomland hardwood trees for the Neches River Basin in east Texas. The models that were developed each consisted of eight transformations of MSS band brightness values. Corelation (Adj. R^2 values) was 0.8789, 0.8140, 0.8091, and 0.7775 for each model respectively. The models were developed in order to estimate each of the parameters for any given year through interpretation of LANDSAT MSS scenes of the study area. Methods used in model development appear to have applicability to other resources in other regions.

INTRODUCTION

This study addressed LANDSAT Multispectral Scanner (MSS) brightness values associated with bottomland hardwood forests downstream of the proposed Rockland damsite on the Neches River in east Texas. LANDSAT acquire MSS data have been analyzed in an attempt to identify spectral signatures of the bottomland hardwoods in wet versus dry years on selected sample areas. This study continued an earlier project (Hathorn and Tilton, 1987), the primary purpose of which was to identify Neches and Angelina River flood flows necessary to sustain acceptable levels of floodplain forest and estuarine productivity. There were four major areas of effort associated with the earlier project. They were: (1) creation of an hydrologic data set; (2) sample site selection and field data collection; (3) MSS data interpretation, and; (4) integrated data analysis.


FT. WORTH
DALLAS
SAM RAYBURN LAKE
NECHES RIVER BASIN
PROPOSED ROCKLAND LAKE
LAKE B. A. STEINHAGEN
AUSTIN
STUDY AREA
BEAUMONT
HOUSTON

Note : Study Area in Neches Basin downstream of Rockland and Sam Rayburn.

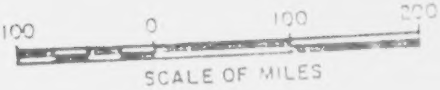

100
0
100
200
SCALE OF MILES

Figure 1 : Project Location

The original project involved efforts of the Fort Worth District, U.S. Army Corps of Engineers, and the Fort Worth Office of Ecological Services, U.S. Fish and Wildlife Service (USFWS). Other participants and consultants respectively, were the Texas Natural Resources Information System (TNRIS) and the Texas Parks and Wildlife Department (TPWD). TNRIS initially extracted spectral response of five temporal LANDSAT scenes from six sample plots within the study area. Initial relationships were found for basal area increment of tree growth versus climatic variability and depth, duration, and frequency of flooding inundation of bottomland hardwoods. No correlation was found between the raw (individual band) MSS brightness values and any of the variables of tree growth, climate, or flooding in the original effort. Due to time constraints imposed by the tight schedule of that initial feasibility planning project, no detailed feature extraction from the MSS data was attempted.

The purpose of the second study, described here, was to more thoroughly examine the variability of MSS spectral response of bottomland hardwoods of the Neches River Basin and to develop models to estimate drought indices flooding conditions, and indices of tree growth.

STUDY AREA

The Neches River Basin lies entirely within Texas (Figure 1). It is bounded on the north and east by the Sabine River Basin, on the west by the Trinity River Basin, and on the south by the Neches-Trinity Coastal Basin. The northeastern third of the Neches Basin is drained by the Angelina River (approximately 190 river miles or 306 km) while the remaining area is drained by the Neches River (approximately 410 river miles or 660 km), Pine Island Bayou, and Village Creek. The Angelina River originates near Freeneytown in Rusk County at an elevation of 290 feet (88.4 m) above mean sea level (msl) and joins the Neches River in B.A. Steinhagen Lake near Neches river mile 130 (km 209) at an elevation of 83 feet (25.3 m) above msl. The specific study area consists roughly of the 100-year floodplain of about 40 miles (64 km) of the Angelina River below Sam Rayburn Dam and about 160 miles (257 km) of the Neches River below the proposed Rockland damsite. As delineated, the floodplain study area consists of about 223,560 acres (904.7 km^2).

There are currently 10 major manmade lakes within the Neches Basin. Sam Rayburn and B.A. Steinhagen Lakes are Corps of Engineers projects and the remainder are owned and operated by non-Federal interests. All major manmade lakes in the Neches Basin are shown on Figure 2. Also located within the basin are all or parts of Davy Crockett National Forest, Angelina National Forest, and the Big Thicket National Preserve.

Soils of the study area have a well developed moderately deep profile. The origins of these soils are both alluvial and

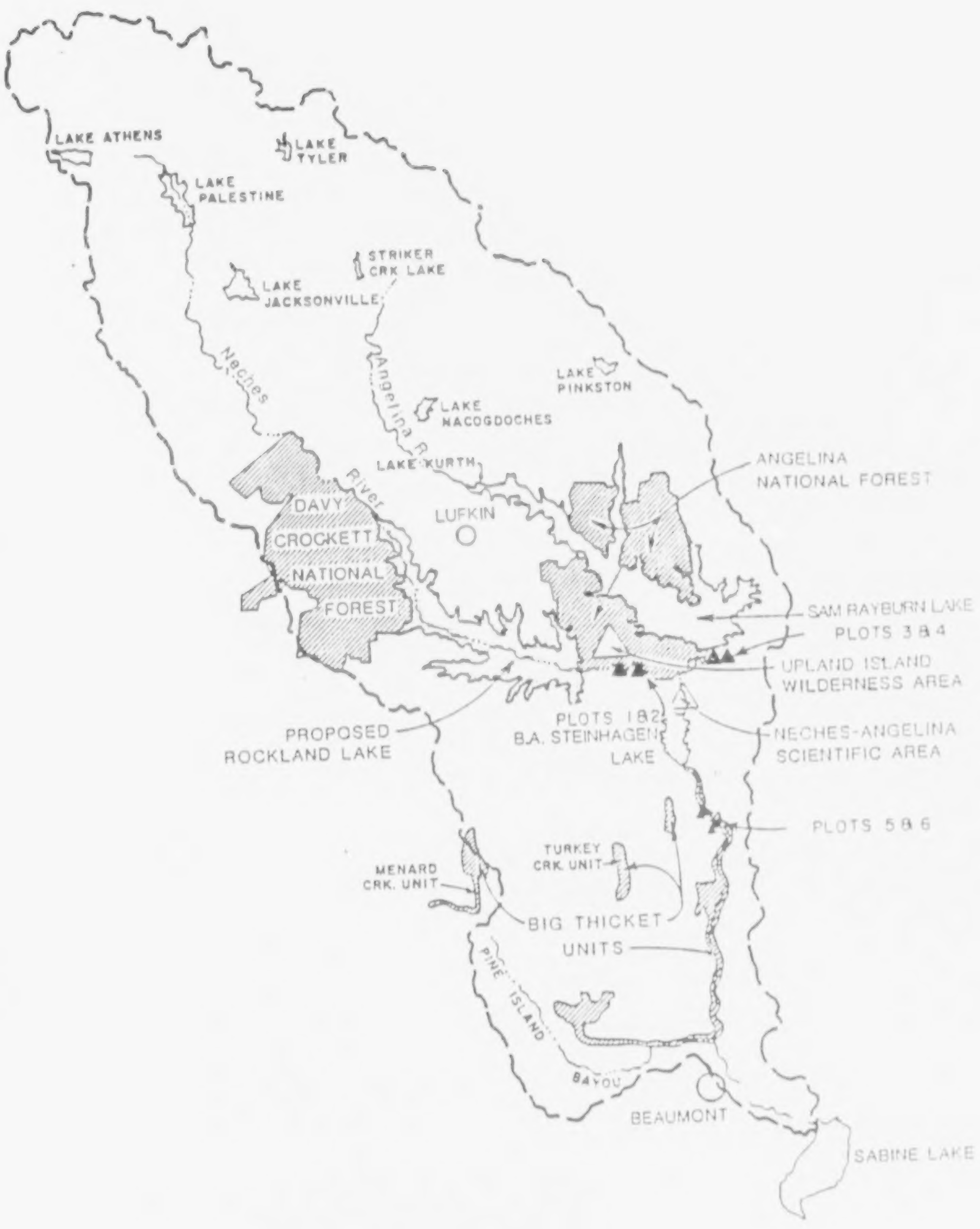

LAKE ATHENS
LAKE TYLER
LAKE PALESTINE
STRIKER CRK LAKE
LAKE JACKSONVILLE
Neches
Angelina R
LAKE PINKSTON
LAKE NACOGDOCHES
LAKE KURTH
ANGELINA NATIONAL FOREST
River
DAVY CROCKETT NATIONAL FOREST
LUFKIN
SAM RAYBURN LAKE
PLOTS 3 & 4
UPLAND ISLAND WILDERNESS AREA
PLOTS 1&2
B.A. STEINHAGEN LAKE
NECHES-ANGELINA SCIENTIFIC AREA
PROPOSED ROCKLAND LAKE
PLOTS 5 & 6
TURKEY CRK. UNIT
MENARD CRK. UNIT
BIG THICKET UNITS
PINE ISLAND BAYOU
BEAUMONT
SABINE LAKE

Figure 2: Neches - Angelina Watershed Map

marine. There are alternating terraces of each classification depending on the location of prehistoric beaches and coves. Alluvial soils occur in narrow to wide strips on floodplains of local drainages and through flowing streams. Major characteristics of study area soils are low permeability, high water table, frequent flooding, and high erodability. The floodplain soils throughout the study area are characterized by ridge and swale topography, created by the meandering river channel. Vegetation becomes established on newly formed ridges leading to more deposition at each flood. This alternating pattern of erosion and deposition due to river meandering creates alternating swales of clay deposition along with sandy ridges with the floodplain.

Long-term U.S. Geologic Survey (USGS) gauging stations downstream of Sam Rayburn and B.A. Steinhagen Lakes and the proposed Rockland and damsite were used to develop the hydrologic data base for this study. See Figure 2 for approximate locations of the three gaging stations. Although the period-of-record for each station varies, recorded data for all stations consists of daily discharge information. Maximum recorded daily discharge over an 83 year period-of-record is 49,700 cubic feet per second (cfs) at Station 1 (upper Neches near the proposed Rockland damsite); 58,400 cfs over a 58 year period-of-record at Station 2 (Angelina near Sam Rayburn Dam); and 92,100 cfs over an 82 year period-of-record at Station 3 (lower Neches downstream of B.A. Steinhagen Dam). At all three stations the maximum daily discharge occurred during the month of May. The average annual period-of-record discharges by station are 2,065 cfs, 3,019 cfs, and 6,016 cfs for Stations 1, 2, and 3, respectively. Figure 3 summarizes the hydrologic record for the 10-year study period at the 3 stations.

The U.S. Fish and Wildlife Service divided Texas into 8 regions and 36 subregions based upon vegetation. The oak-hickory-pine forest, southern mixed forest, and southern floodplain forest subregions of the Pineywoods region, the oak woodland and bottomland forest subregions of the Central Texas region; and the coastal prairie subregion of the Gulf Coast region all occur within the Neches River Basin. Generally, most of the uplands of the study area are dominated by pines. Long-leaf pine was historically abundant but much has been logged and replaced by loblolly and short-leaf pines. Many hardwoods, such as oaks, hickory, and maples are also present in the overstory of the upland plant communities.

Like the uplands, floodplains of the study area support a diverse forest community. The floodplain community of the Neches River basin varies from slough forests dominated by bald cypress and swamp tupelo; through oak, sweetgum, and black gum dominated forest; to loblolly pine, beech, and magnolia dominated forests on mesic terraces in small creek bottoms. Additional community

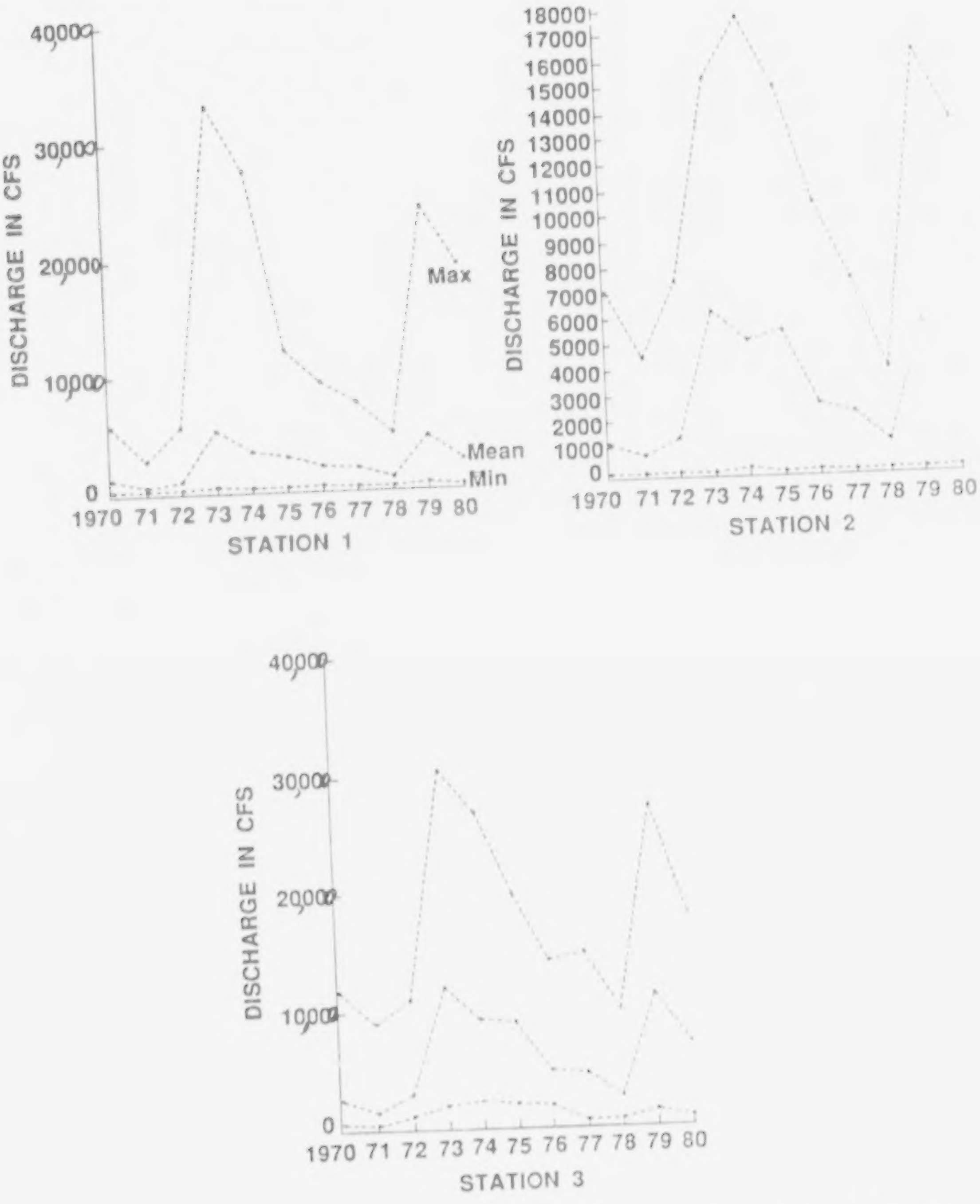


FIGURE 3: HYDROLOGIC SUMMARY FOR 10-YEAR STUDY PERIOD
NECHES RIVER BASIN, TEXAS (Based on Daily Records)

types include baygall forests and flat bottomland forests dominated by oaks. Groundlayer vegetation becomes increasingly sparse in proportion to increasing frequency and duration of flooding. Woody vines are abundant throughout the bottoms.

METHODS

Aerial photography, National Wetlands Inventory maps, USGS topographic maps, and soil surveys were analyzed to identify prospective vegetation sample plots. Using this information, twenty-five plots which were fairly uniform over at least 20 acres, which appeared to be undisturbed by logging or other commercial operations, and which had similar soil types and wetland inventory designations were identified for further field consideration. Field inspection eliminated a number of plots from consideration because of recent disturbances which had not been detected by mapping used in the preliminary screening and led to tentative selection of six sites for intensive investigation. The assistance of Soil Conservation Service soil scientists was obtained to maximize uniformity of soils between plots. Finally selected sites were located, two each, on the upper Neches river downstream of the proposed Rockland Damsite, downstream of Sam Rayburn Dam on the Angelina River, and on the lower Neches River downstream of B.A. Steinhagen Lake. All sample plots are on fairly similar soils and none of the plots have any obvious indication of disruptions due to fire, disease, or logging. Within each plot there is a gentle range or gradient from _Taxodium distichum_ (cypress) ridge-slough to _Quercus phelos_ (willow oak) flats as a result of the ridge-swale topography of the study area. Each plot is regularly flooded which greatly influences its vegetative community structure.

Because of its relatively high frequency of occurrence, importance, and dominance at all plots, willow oak was selected for dendrochronological analyses. One increment core was taken from 15 trees on each plot in what appeared to be an area of average growth on the trunk. Tree growth-ring counting and measurement was done at Rice University. Raw tree-ring data were converted to basal area increment of growth for each tree for each year. Although most cores did not penetrate to the center of each tree, basal area increments were back-calculated from the recorded diameter at breast height (DBH), raw tree-ring widths, and assumed shape of the tree (round). Assuming that tree height and crown volume remain relatively constant, basal area increment was considered to be a better estimate of tree growth than raw ring width because geometric effects of tree growth are accounted for.

To compensate for varying growth rates of trees within the uneven aged samples, a normalization was performed. Deviation of the basal area increment from the mid-year of a five-year floating average was calculated for each year for each tree. This floating average creates a basal area index which normalizes for age-related growth differences of each tree. Figure 4 presents graphic summary of basal area indices, averaged for all trees for all plots for a ten year period through which LANDSAT data are available.

The Palmer Drought Index (Palmer, 1965) was employed to define the effects of climate on tree growth and community structure of the sample plots, separate from inundation due to stream flooding. The procedure requires a climatological analysis of a long record in order to derive five constants which define certain moisture characteristics of the climate of the area of interest. For this study an 88 year period-of-record (1895-1983) was available. From the climatological record, a month-by-month water balance accounting, including precipitation and evapotranspiration, was conducted. Potential values for rainfall runoff, moisture recharge, and moisture loss were also derived.

From the derived coefficients, the amount of precipitation necessary to sustain evapotranspiration, runoff, and moisture storage for each month is computed. The computed precipitation represents an adjusted normal precipitation for each month which is dependant upon antecedent weather and moisture balance. Over the long term, the computed precipitation is equal to the mean of the actual precipitation. From this information, the Palmer Drought Severity Index (PDSI) which evaluates each successive month on an increment basis in terms of its contribution to drought or moisture over a longer period is calculated. An annual drought index was calculated (net summation of monthly values) and Figure 5 presents that annual drought index for the ten year period of this study. Table 1 provides interpretation of PDSI values.

In order to obtain a range of wet versus dry years, the hydrologic record from 1972 to present was analyzed and categorized on a relative scale with emphasis on spring flooding. A listing of available LANDSAT scenes of the study area was then examined to determine availability of cloud-free scenes corresponding to a range of flow years from very wet to very dry. Late spring and early summer scenes were first examined under the assumption that spectral responses would show the greatest variation during that period. There were, however, insufficient scenes available, which corresponded to a range of water years which were not obscured by cloud cover, were not affected by recent rainfall events, and were within a tight one to two week period. As a result, the month of October was examined for availability of scenes.

Cloud-free LANDSAT MSS scenes were determined to be available for a period from October 3 through October 12, for five different years. Precedent rainfall conditions as documented by the National Weather Service's monthly summary data were examined for each of those five years and it was determined that no more than a trace of rainfall was observed at any station in the study area for at least two weeks prior to date of the

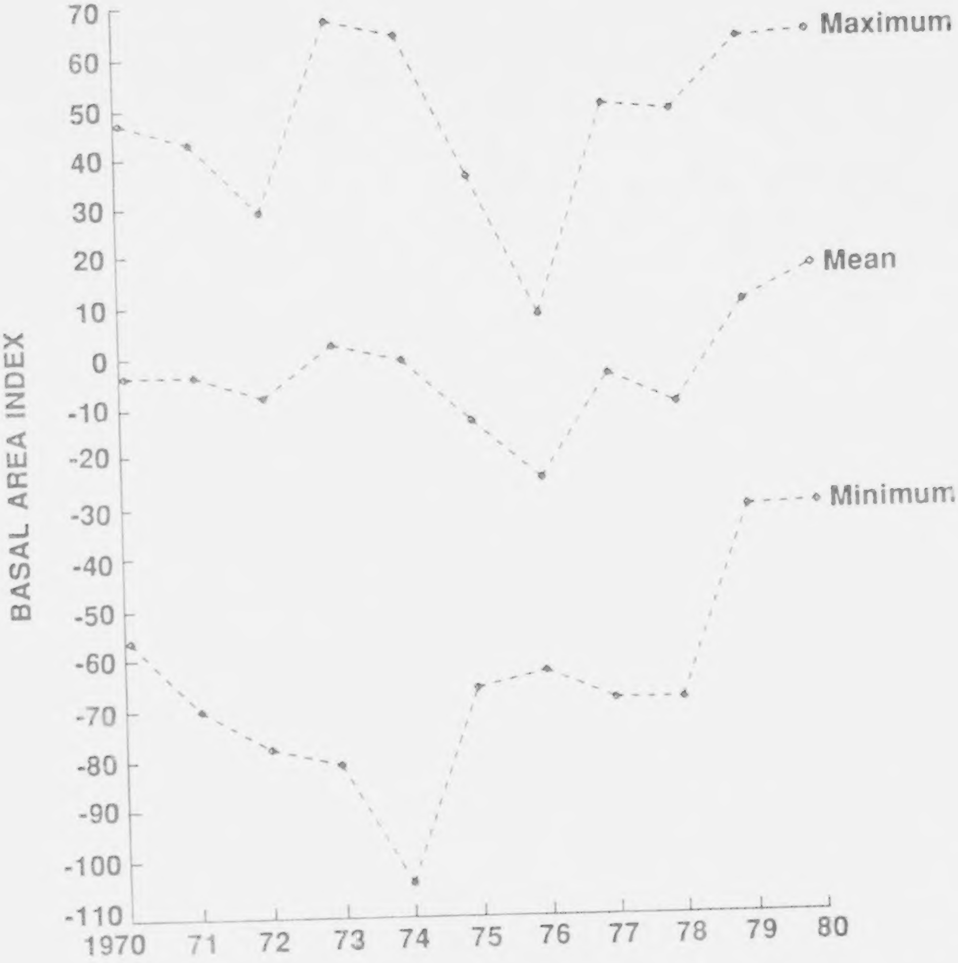


FIGURE 4: AVERAGE BASAL AREA INDEX VALUES FOR ALL PLOTS NECHES RIVER BASIN, TEXAS

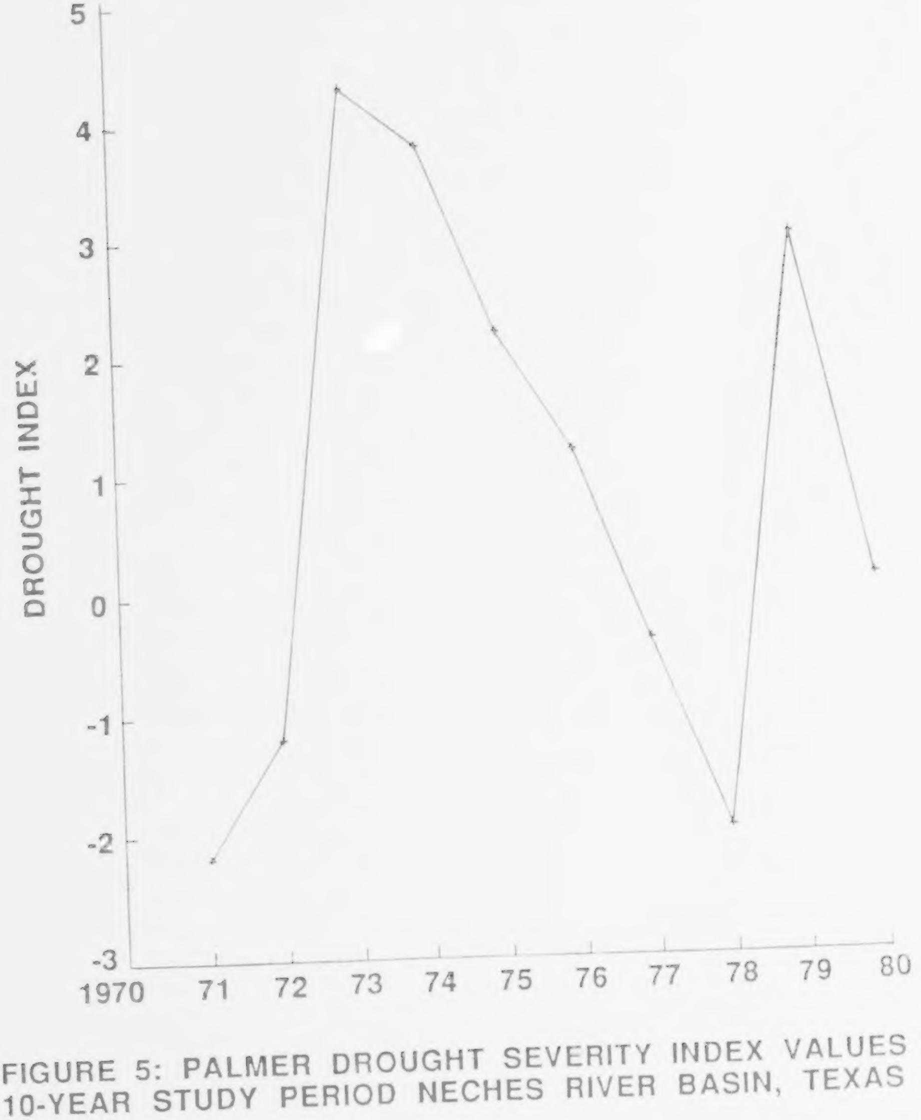


FIGURE 5: PALMER DROUGHT SEVERITY INDEX VALUES FOR 10-YEAR STUDY PERIOD NECHES RIVER BASIN, TEXAS

Table 1 - INTERPRETATION OF PALMER DROUGHT SEVERITY INDEX VALUES (Palmer, 1965)

ABOVE +4	EXTREME WET
+3 to +4	SEVERE WET
+2 to +3	MODERATE
-2 to +2	NEAR NORMAL
-2 to -3	MODERATE DROUGHT
-3 to -4	SEVERE DROUGHT
BELOW -4	EXTREME DROUGHT

scene. As a result, scenes for 3 Oct. 1972, 11 Oct. 1974, 9 Oct. 1976, 8 Oct. 1978, and 12 Oct. 1979 were obtained. Calendar years 1974 and 1979 are representative of years with relatively wet spring seasons. Years 1972 and 1976 are representative of moderate Spring flooding and 1978 is a dry year with no spring flooding. Refer to Figure 3 for a summary of the hydrologic record for the three flow gaging stations.

The Texas Natural Resources Information System georectified each LANDSAT scene and extracted the spectral response statistics (bands 1, 2, 3, and 4) of each scene using a Perkin-Elmer computer and software developed in-house. Georectification was performed at a pixel resolution of 79 x 50 meters using nearest neighbor resampling. Average brightness values by band were extracted from each scene by superimposition of georeferenced polygons of each sample plot. Brightness value statistics provided by TNRIS were subsequently verified through random selection of the 1972 scene with data extraction by sample plot using the Earth Resources Data Analysis System (ERDAS) hardware and software at North Texas State University. Brightness value data were included in the main data array for comparison with other parameters such as flow, climate, and dendrochronologic data. At this point correlation analyses were performed on the individual band brightness values and the variables of annual drought index, basal area index of tree growth, flow, depth and frequency of flood inundation. No correlations ($R < 0.20$ at p values greater than 0.05) were found between the individual band brightness values and the other variables.

A number of feature extraction transformations were performed on the raw MSS data in an attempt to accentuate any intrinsic patterns which may be obtained from remote sensing data. Data transformations included band ratioing, linear combinations, natural log transformations, and use of previously employed indices for response of green vegetation. Lillesand, et al. (1983) employed such transformations in attempting to use LANDSAT data to predict trophic state of Minnesota lakes. More recently, Vujakovic (1987) showed that certain transformations were applicable for establishing a relationship between LANDSAT brightness values and broad-scale variations in woody cover. Jensen (1986) summarized the work of several authors (Rouse, 1973; Kauth and Thomas, 1976; Richardson and Weigand, 1977; and Ashburn, 1978) in development and use of various spectral response indices of green vegetation.

Table 2 present transformations of raw MSS data values which were developed for analysis against the variables of Annual Drought Index, Maximum Flow, Mean Flow, and Basal Area Index. It should be noted that the last four indices, SBI, GVI, YSI, and NSI were developed for analysis of growth and productivity of tasseled crops (Jensen, 1986) but were employed in this study for heuristic reasons. These transformations were included in the final data array as independent variables and the Statistical Analysis System (SAS, 1985) software was used to identify relationships of the MSS data to the other variables. Table 3 lists the data for all six plots used in this study.

Table 2
MSS Data Transformations Used in Analysis

Each Band * Each Band
Each Band / Each Band
Each Band Squared
Natural Log of Each Band
Normalized Difference of Bands 2 & 3 (Rouse, 1973)
  ND3=(Band3-Band2)/(Band3+Band2)
Normalized Difference of Bands 4 & 3 (ibid.)
  ND4=(Band4-Band3)/(Band4+Band3)
Transformed Vegetation Indices (ibid.)
  TV3=(ND3-0.5)/(ND3+0.5)
  TV4=(ND4-0.5)/(ND4+0.5)
DVI (Richardson and Weigand, 1977)
  DVI=2.4*Band4-Band2
AVI (Ashburn, 1978)
  AVI=2*Band4-Band2
Soil Brightness Index (Kauth and Thomas, 1976)
  SBI=.332*Band1+.603*Band2+.675*Band3+.262*Band4
Green Vegetation Index (ibid.)
  GVI=(-.283*Band1)+(.660*Band2)+.577*Band3+.338*Band4
Yellow Stuff Index (ibid.)
  YVI=(-.899*Band1)+.428*Band2+.076*Band3+(-.041*Band4)
Non-Such Index (ibid.)
  NSI=(.018*Band1)+.113*Band2+(-.452*Band3)+.882*Band4

TABLE 3
RAW DATA COLLECTED
FOR STATISTICAL ANALYSES

YEAR	PLOT	ANNUAL DROUGHT INDEX	MEAN FLOW	MAXIMUM FLOW	BASAL AREA INDEX	MSS BAND 1	MSS BAND 2	MSS BAND 3	MSS BAND 4
1972	1	-1.2	795.2	5440	4.507	21.92	13.08	31.32	19.28
1974	1	3.8	3205.0	27500	-0.489	22.32	13.68	29.96	17.21
1976	1	1.2	1863.0	9120	-35.134	11.19	9.73	30.04	17.82
1978	1	-2.0	790.3	4590	-21.631	13.93	9.89	32.04	20.30
1979	1	3.0	4256.9	24100	9.802	12.24	10.91	29.64	30.51
1972	2	-1.2	795.2	5440	-3.798	22.23	13.55	32.76	19.50
1974	2	3.8	3205.0	27500	11.106	22.76	13.65	31.33	17.68
1976	2	1.2	1863.0	9120	-28.080	10.77	10.32	31.35	18.67
1978	2	-2.0	790.3	4590	-19.871	14.29	9.55	32.60	21.21
1979	2	3.0	4256.9	24100	5.078	13.08	11.75	32.24	31.91
1972	3	-1.2	1367.7	7480	-13.537	21.11	13.08	31.14	18.32
1974	3	3.8	5135.7	17670	-20.635	21.26	12.41	30.32	16.73
1976	3	1.2	2619.3	10465	-11.595	11.94	10.16	31.63	16.33
1978	3	-2.0	1117.5	3940	12.258	13.58	9.58	29.41	18.36
1979	3	3.0	5723.0	16280	23.860				
1972	4	-1.2	1367.7	7480	-2.745	22.41	12.48	32.23	18.96
1974	4	3.8	5135.7	17670	-22.237	20.46	12.34	30.26	17.31
1976	4	1.2	2619.3	10465	-27.903	11.72	11.45	32.27	17.90
1978	4	-2.0	1117.5	3940	2.264	14.62	9.73	30.02	17.85
1979	4	3.0	5723.0	16280	5.540				
1972	5	-1.2	2719.4	10900	-18.348	24.15	13.95	30.77	17.51
1974	5	3.8	9115.2	26900	19.397	20.50	12.50	31.86	18.20
1976	5	1.2	4594.6	14100	-29.010	13.62	14.15	29.66	15.02
1978	5	-2.0	2315.5	9760	-16.003	14.09	13.25	30.14	18.96
1979	5	3.0	10979.1	27200	9.275	10.96	10.72	27.34	27.90
1972	6	-1.2	2719.4	10900	-18.678	13.58	14.37	31.36	17.74
1974	6	3.8	9115.2	26900	13.254	21.43	14.19	31.36	17.74
1976	6	1.2	4594.6	14100	-16.210	12.30	11.17	31.87	17.18
1978	6	-2.0	2315.5	9760	-24.940	13.16	11.59	30.86	18.75
1979	6	3.0	10979.1	27200	6.062	13.13	13.05	30.09	31.28

RESULTS

Using the SAS software, the stepwise regression procedure was performed on the raw MSS data and all transformations to develop models for Annual Drought Index, Maximum Flow, Mean Flow, and Basal Area Index. Only data from sample plots 1, 3, 4, 5, and 6 were included in the Maximum R^2 Stepwise procedure. Data from sample plot 2 were withheld in order to test the models after development. The stepwise procedure did produce productive models for each of the four variables which coincidentally optimissed at about eight independent variables per model. In other words, the intrinsic dimensionality of each model consists of eight MSS bands or band transformations. Table 4 presents results of the stepwise model building procedure. Adjusted R^2 values for each model are 0.8789 for Annual Drought Index, 0.8140 for Mean Flow, 0.8091 for Maximum Flow, and 0.7775 for the Basal Area Index model. All model predictions are at a significance level (p) of 0.0001. Shown in Figure 6 are the predicted versus actual values for each model as well as their respective 95% confidence limits.

Figures 7 through 10 show the fit of predicted values as regressed against the actual values for each sample plot. As can be seen from these figures, the MSS models are fairly good predictors of Annual Drought Index, annual mean flow and the maximum instantaneous flow that occurred for each year at each sample plot. Likewise, the Basal Area Index model is capable of reasonable simulation of actual measured basal area index. A notable anomaly of these figures is predictability for sample plot 3 which is located just downstream of Sam Rayburn Dam. No river flow exceeded bank capacity at either plot 3 or plot 4 during the 1970 to 1980 period-of-study due to the presence of Sam Rayburn Dam. That fact could account for the relatively low R^2 values for all models at plot 3 but does not explain the differences in predictability between plots 3 and 4. It should be noted that the predictability of each model can be increased by including more of the transformed MSS band values in the models but adjusted R^2's increase only slightly with increasing model complexity.

As has been stated, brightness values for sample plot 2 were omitted from model building in order to test their predictability of actual plot 2 values. Actual values for drought index, mean flow, maximum flow, and basal area index at plot 2 were regressed against plot 2 MSS brightness values as components of the transformation variables and their respective B values. Analysis of Figures 7 through 10 indicates that the models predict trends for all dependent variables, but with the exception of maximum flow, predicted values are either higher or lower than actual values for sample plot 2. To increase the accuracy of predicted values, compensation coefficients could be included in the models of drought index, mean flow, and basal area index. This was not done for this study.

Table 4

MODELS DEVELOPED THROUGH STEPWISE PROCEDURE

(Maximum R^2 Option)

	DROUGHT INDEX	MEAN FLOW	MAXIMUM FLOW	BASAL AREA INDEX
MODEL COMPONENTS/ B Value	Intercept	Intercept	Intercept	Intercept
	511.43	5157602	-76367	387.15
	Band1	Band3	Band1/Band2	Band1
	21.84	65223	-145078	-48.14
	Band1/Band4	Band2/Band1	Band1/Band3	Band2/Band3
	79.58	-99053	-373445	-2546
	Band2/Band1	Band2/Band3	Band1/Band4	Band4/Band3
	-31.75	-214721	215248	2602
	Band2/Band4	Band4/Band1	Band4/Band1	Band4/Band1
	-377.9	16855	77293	-347.59
	Log Band1	Band1*Band4	Band2*Band4	Band1*Band2
	-19.65	-185.29	335.13	2.14
	$Band1^2$	Band2*Band4	$Band\ 1^2$	ND4
	-0.64	401.729	-705.86	-766.88
	YVI	Log Band3	YVI	NSI
	-43.20	-2048365	-45837	-48.27
	$Band3^2$	ND4	$Band4^2$	$Band2^2$
	0.07	-176439	-119.63	0.97
ADJUSTED R^2 VALUE	0.8789	0.8140	0.8091	0.7775

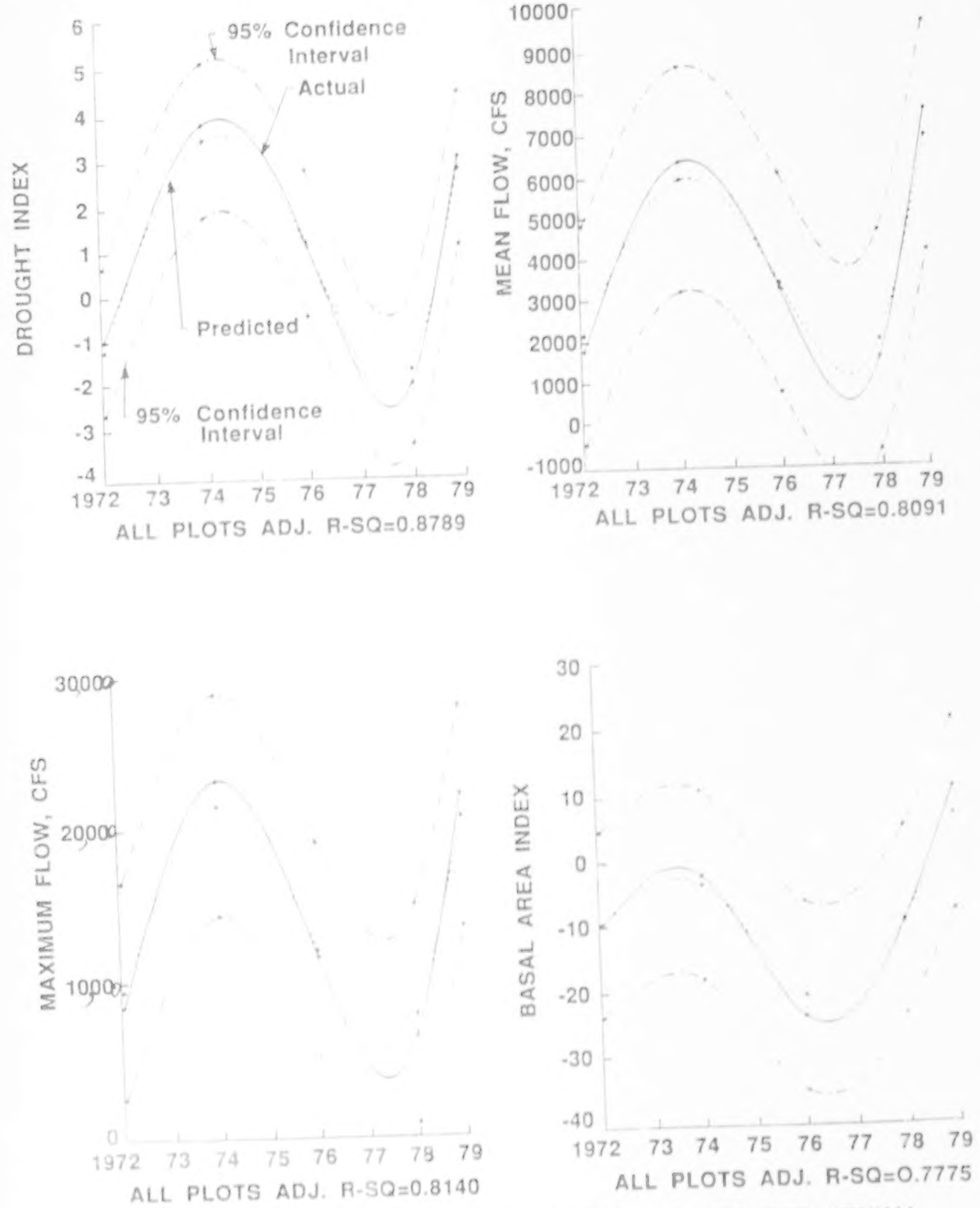
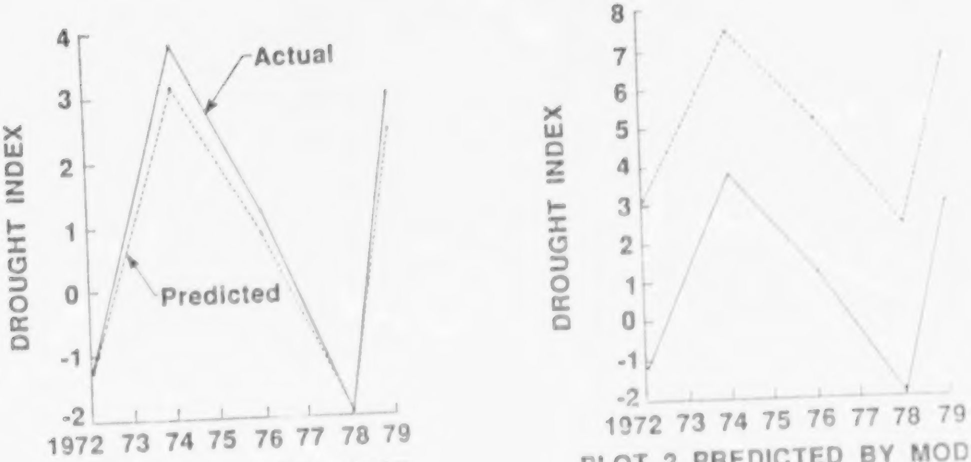
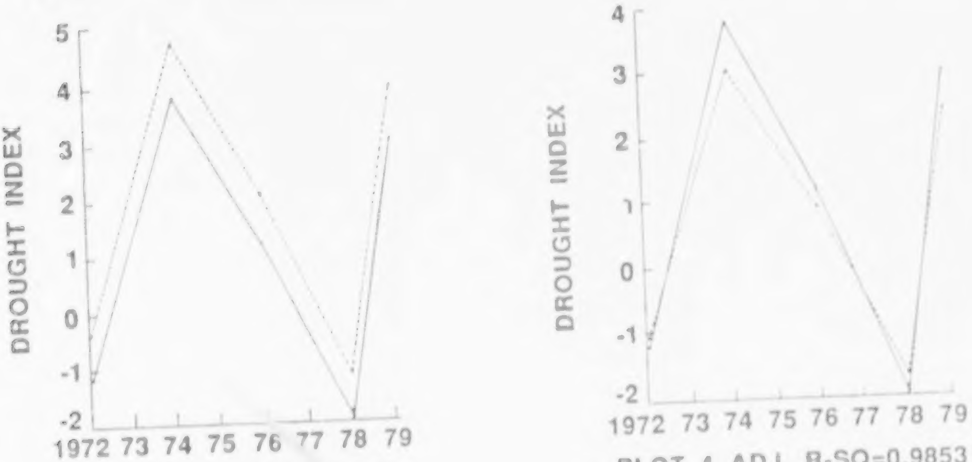


FIGURE 6: PREDICTED VERSUS ACTUAL VALUES FOR ANNUAL DROUGHT INDEX, MEAN FLOW, MAXIMUM FLOW, AND BASAL AREA INDEX OF TREE GROWTH FOR ALL PLOTS



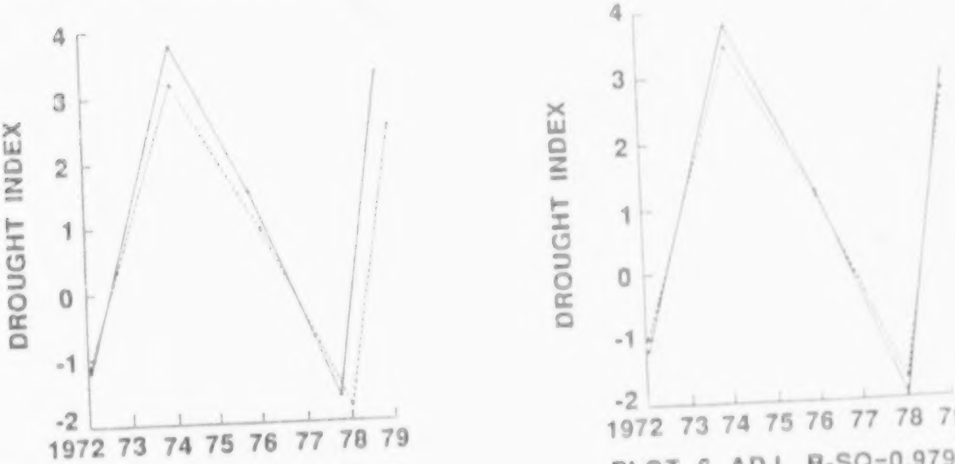
PLOT 1 ADJ. R-SQ=0.9385

PLOT 2 PREDICTED BY MODEL



PLOT 3 ADJ. R-SQ=0.7262

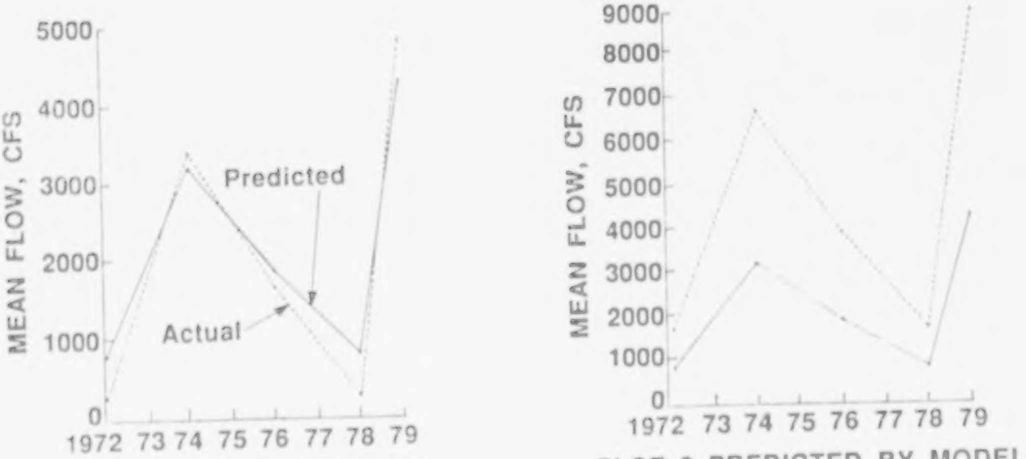
PLOT 4 ADJ. R-SQ=0.9853



PLOT 5 ADJ. R-SQ=0.8770

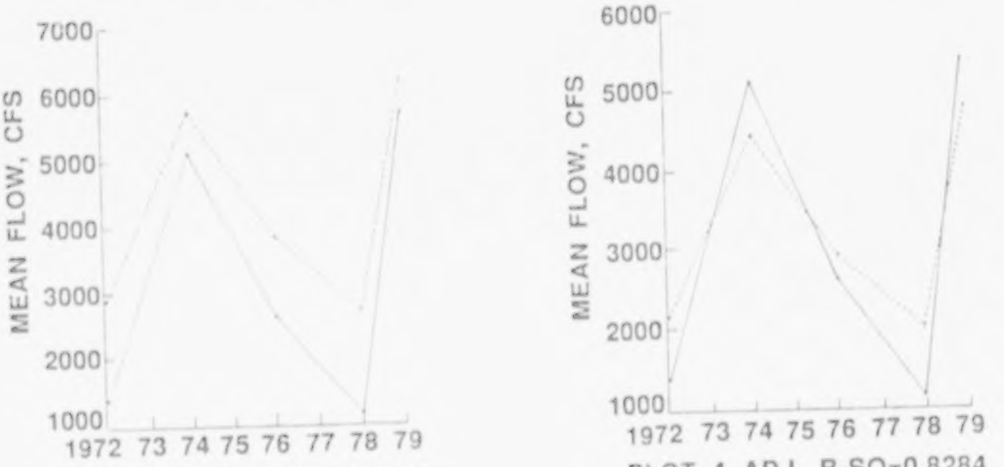
PLOT 6 ADJ. R-SQ=0.9798

FIGURE 7: PREDICTED VERSUS ACTUAL ANNUAL DROUGHT INDEX BY PLOT



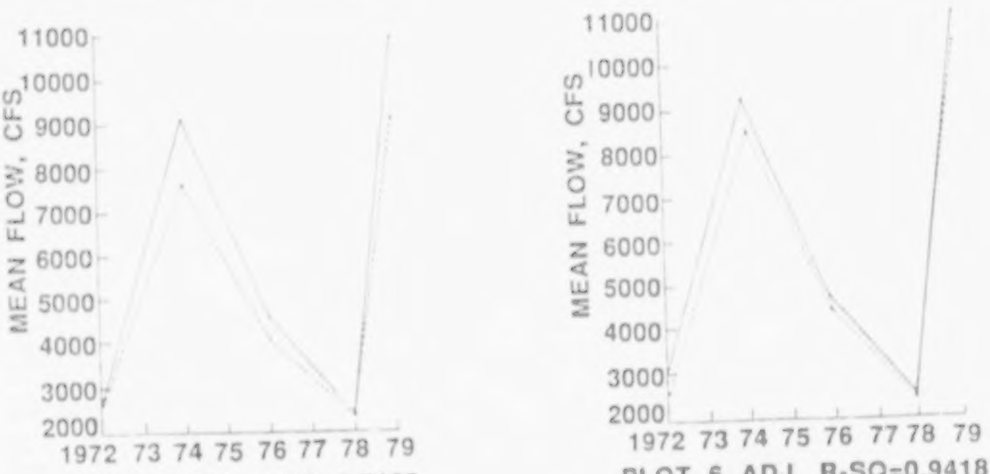
PLOT 1 ADJ. R-SQ=0.5235

PLOT 2 PREDICTED BY MODEL



PLOT 3 ADJ. R-SQ=0.5745

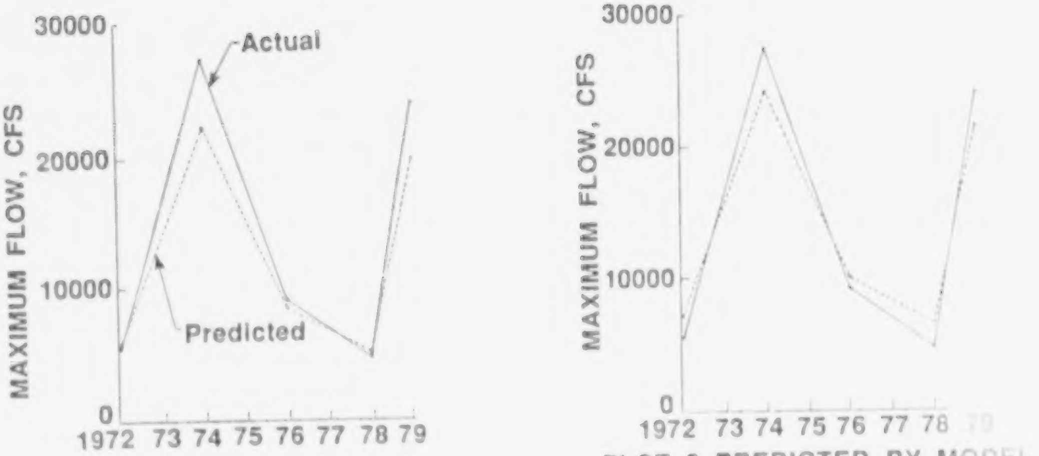
PLOT 4 ADJ. R-SQ=0.8284



PLOT 5 ADJ. R-SQ=0.7433

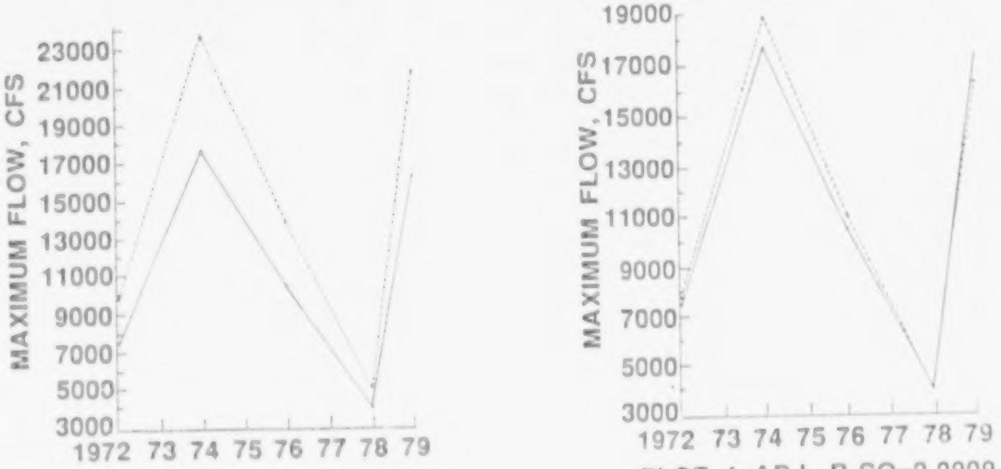
PLOT 6 ADJ. R-SQ=0.9418

FIGURE 8: PREDICTED VERSUS ACTUAL MEAN FLOW BY PLOT



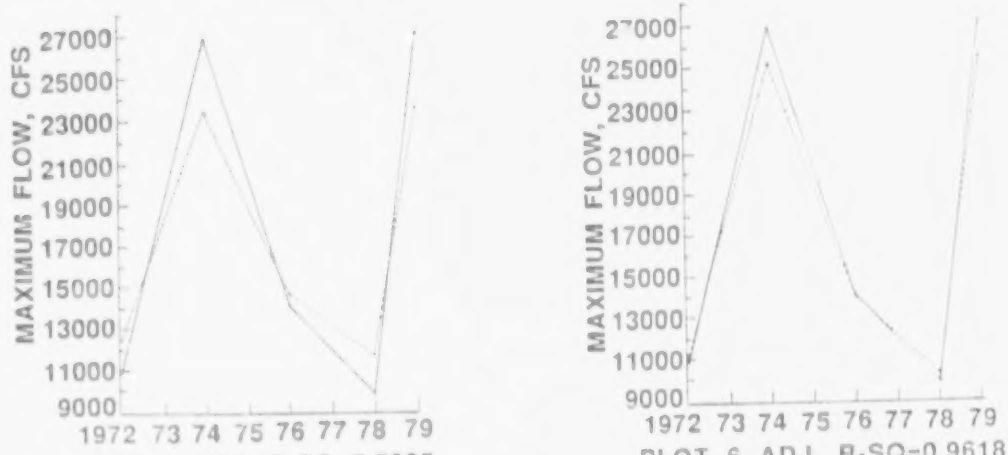
PLOT 1 ADJ. R-SQ=0.8283

PLOT 2 PREDICTED BY MODEL



PLOT 3 ADJ. R.-SQ=0.6352

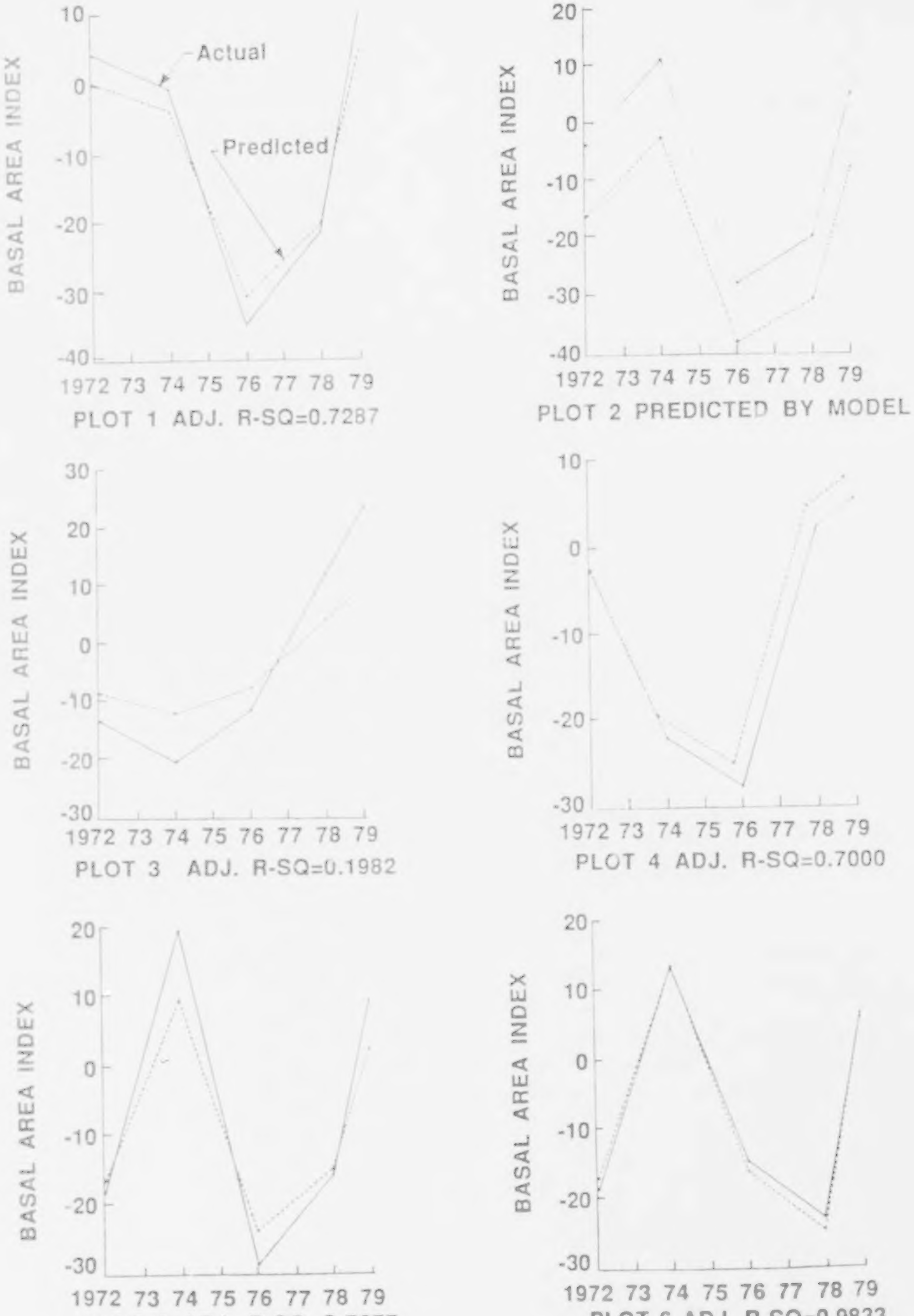
PLOT 4 ADJ. R-SQ=0.9909



PLOT 5 ADJ. R-SQ=0.7325

PLOT 6 ADJ. R-SQ=0.9618

FIGURE 9: PREDICTED VERSUS ACTUAL MAXIMUM FLOW BY PLOT



PLOT 1 ADJ. R-SQ=0.7287

PLOT 2 PREDICTED BY MODEL

PLOT 3 ADJ. R-SQ=0.1982

PLOT 4 ADJ. R-SQ=0.7000

PLOT 5 ADJ. R-SQ=0.7877

PLOT 6 ADJ. R-SQ=0.9833

FIGURE 10: PREDICTED VERSUS ACTUAL BASAL AREA INCREMENT OF TREE GROWTH BY PLOT

CONCLUSIONS

Statistical models can be developed using LANDSAT MSS band brightness values and transformations of those values to estimate certain natural phenomena. The "state" of a given phenomenon can be field determined and then a model can be developed which predicts the "state" based on LANDSAT MSS. The model can ultimately be tested by comparing predicted to actual values. Further, once the models are developed and adequately refined, they can be used to estimate the "state" of the resource parameter at any past or future time for which LANDSAT MSS data may become available.

For this study, MSS models were developed for the phenomena of drought status, for mean and maximum stream flows occurring during a calendar year, and for an index of the tree growth of bottomland hardwoods within the Neches River Basin of Texas. Each of the four models was developed from five temporal scenes of the study area and consists of eight MSS brightness values and/or transformations of those values. The models were verified as being able to reasonably predict (based on R^2 values) actual drought index, mean flow, maximum flow, and basal area index values. The models were further verified by comparing predicted values with actual values of a sample plot not included in model development.

Although such model development requires extensive "front end loading" in terms data acquisition (climatologic, hydrologic, and dendrochronologic) that cost should be offset by long-term planning and/or stream flow management opportunities. If planning for a proposed reservoir in the basin continues, the models can be used to estimate tree growth from LANDSAT MSS data as it relates to various flows and climatic conditions. If a stream regulation project (reservoir) is constructed, the models can be used to estimate effectiveness of prescribed releases to optimize tree growth without substantial additional field effort. Development of MSS models as indicators of natural resource parameters would appear to have applicability to other regions and resources.

REFERENCES

ASHBURN, P., 1978, "The Vegetative Index Number and Crop Identification," Proceedings, Technical Session, LACIE Symposium, Houston, Texas, National Aeronautics and Space Administration, pp. 843-856.

HATHORN, P.M.; TILTON, D.A., 1987, "Multiple Parameter Analysis of Effects of Flooding on Bottomland Hardwood Productivity Downstream of the Proposed Rockland Lake Project" Limited Reevaluation Study of Rockland Lake (draft), App. D, Fort Worth District, Texas, U.S. Army Corps of Engineers, 70 pp.

JENSEN, J.R., 1986, Introductory Digital Image Processing, A Remote Sensing Perspective, Prentice-Hall, Englewood Cliffs, New Jersey, 375 pp.

KAUTH, R.J., and THOMAS, G.S., 1976, "The Tasseled Cap-A-Graphic Description of the Spectral-Temporal Development of Agricultural Crops as Seen by Landsat," Proceedings, Symposium on Machine Processing of Remotely Senses Data, Laboratory for the Applications of Remote Sensing, West Lafayette, Indiana, pp. 41-45.

LILLESAND, T.M., JOHNSON, W.L., DEUELL, R.L., LINDSTROM, O.M., and MEISNER, D.E., 1983, "Use of Landsat Data to Predict the Trophic State of Minnesota Lakes," Photogrametric Engineering and Remote Sensing, Vol. 49, No. 2, pp. 219-229.

PALMER, W.C., 1965, Meterological Drought. Research Paper No. 45 U.S. Dept. of Comm., Weather Bureau, 53 pp.

RICHARDSON, A.J., and WEIGAND, W.C., 1977, "Distinguishing Vegetation from Soil Background Information," Remote Sensing of Environment, Vol. 8, pp. 307-312.

ROUSE, J.W., HASS, R.H., SCHELL, J.A., and DEERING, D.W., 1973, "Monitoring Vegetation Systems in the Great Plains with ERTS," Proceedings, Third ERTS Symposium, Vol. 1, pp. 48-62.

SAS Institute Inc. 1985. SAS Users Guide, Basics, Statistics Version 5. Cary, North Carolina, 965 pp.

VUJAKOVIC, P., 1987, "Monitoring Extensive Buffer Zones in Africa: An Application for Satellite Imagery," Biological Conservation, Vol. 39, pp. 195-208.

GOES SATELLITE DATA AND GIS TECHNOLOGY HAVE A FUTURE IN HABITAT ANALYSIS*

Jack Stoll

and

Steve Bong

U.S. Army Corps of Engineers Waterways
Experiment Station, Vicksburg, MS

and

Ross S. Lunetta

U.S. Army Corps of Engineers
Detroit, MI

*Abstract not available

INTEGRATION OF LOW ALTITUDE MSS DATA WITH HABITAT EVALUATION PROCEDURES

J. Paxton, U.S. Army Engineer District, Fort Worth
W. Hazard, Earthscan, Inc., Austin, Texas

ABSTRACT

Passage of the National Environmental Policy Act (NEPA) and the development of Aerochrome Infrared (color IR) film has contributed significantly to the spread of remote sensing for habitat evaluation. NEPA has provided the impetus for rapid development of remote sensing techniques and color IR has been shown to be an exceptional tool for gathering large amounts of data in an efficient and cost effective manner. However, the broad-band spectral response characteristics of color IR film tends to mask differences among hardwood tree species that are indicators of habitat quality. New techniques using satellite produced imagery and low altitude multispectral imagery have allowed these spectral response difficulties to be overcome.

A study, designed to address differences between reported techniques of habitat measurement, was commissioned by the Little Cypress Utility District at a proposed reservoir site in the Cypress Bayou Basin of east Texas. Discrepancies were noted in total acreage of habitat types reported in previous studies using manual interpretation of high altitude color IR photography. Integration of Landsat-5 Thematic Mapper and low altitude solid state videographic imagery allowed delineation of habitat variables which previously could only be determined by lengthy field surveys.

INTRODUCTION

Two historical events triggered a rapid increase in the use of aerial photography for natural resource management in the 1970s' - the passage of the National Environmental Policy Act of 1969, requiring habitat evaluations for all federal water projects, and the availability of Aerochrome Infrared film, which provides a means for broad-band spectral identification of terrestrial vegetation for wildlife habitat evaluations.

Until the late 1960s' data collection for wildlife habitat evaluations that were required by the Fish and Wildlife Coordination Act were obtained primarily by field surveys.

Black and white and later color aerial photography were used occasionally to measure linear distances that were difficult to obtain by on-site inspection, such as area calculations and forest edge measurements, distance from shelter to food and canopy cover, and for estimates of slope and aspect.

Resource managers were among the early users of color infrared photography in the 1970s, culminating in the "patchiness" index which is widely used by the Bureau of Reclamation to describe vegetative and foliage diversity.

The production of National High Altitude Photography (NHAP) at a nominal scale of 1-58,200 by the USGS, beginning in 1980, was also a significant milestone in the evolution of remote sensing technology for renewable resource mapping applications.

NHAP photography has become the principal source of land cover data for wildlife habitat evaluations by biologists and ecologists. Statistics obtained by manual interpretation of NHAP photography provide approximately two-thirds of the data needed to calculate habitat suitability under Habitat Evaluation Evaluation Procedures (HEP), and more recently, Habitat Management Evaluation Models (HMEM) promulgated by the National Ecology Center in Fort Collins, Colorado. However, due to its broad-band spectral response characteristics, color infrared tends to mask differences among hardwood species that are important for impact assessments and trade-off negotiations under HEP, and habitat management under HMEM.

The reliability of manual photo-interpretation of color infrared photography, particularly at the NHAP scale of 1:58,200, has also been questioned by U.S. Corps of Engineers personnel who utilize HEP studies for environmental impact statements.

At the suggestion of environmental planners and ecologists in the Corp's Fort Worth district, the Little Cypress Utility District (LCUD), Hallsville, Tx., recently carried out a quantitative investigation of land cover in a proposed 14,000 acre reservoir site in northeast Texas.

The purpose of this paper is to discuss methods used to compare the results obtained by digital image processing carried out under contract with LCUD and three other inventories of wildlife habitat in the Little Cypress bayou bayou which were based on photo-interpretation of high altitude color infrared photography. Interpretation of a 1974 multispectral mapper (MSS) scene by the Texas Parks & Wildlife Department is also examined for comparative purposes.

Digital data were obtained by overlaying low-altitude, multispectral video scans on a portion of a thematic mapper (TM) image of Little Cypress. Image processing was carried out under the direction of the the co-author at Waid and Associates, Austin, Tx., as part contract with LCUD.

The policy and management implications of the findings for the Little Cypress Utility District and for future reservoir development projects are also discussed.

THE STUDY SITE

The Little Cypress bayou is located in the irregular, rolling forested northern edge of the Texas Pineywoods, near the cities of Longview, Marshall and Kilgore in Harrison and Upshur counties near the Texas-Louisiana border (Figure 1).

The climate of Little Cypress is characterized as warm, moist, humid and subtropical with a mean annual rainfall of 44 inches. Polar air masses contribute significantly to the fall and winter climate. Counter clockwise airflow from the Gulf of Mexico dominates in the spring and summer months.

Local topographic features are hilly uplands, flat floodplains and terraces which support a variety of flooded and alluvial hardwoods, riparian vegetation, loblolly (Pinus taeda) and shortleaf (Pinus echinata) pines in in the uplands. The understory components of hardwood forest canopy includes weedy regrowth such as American hornbeam, American holly, osage-orange flowering dogwood and Texas persimmon. The tree midstory was found to have more than one layer typically. Shrub and vegetation in the pine and mixed pine/hardwood areas is well developed, however the number of species and density of the midstory declines as the overstory canopy closes. Canopy density was revealed by maximum liklihood classification of spectral signatures from the Landsat TM scene and the digitized solid state frames obtained by low altitude scanning.

Tree species commonly found in the flooded and alluvial hardwood bottomlands were sweetgum (Liquidambar styraciflua), willow oak (Quercus phellos), overcup oak (Q. lyrats), river birch (Betula nigra), sourthern red oak (Q. falcata), water tupelo (Nyssa aquatica), laurel oak (Q. laurifola), blackgum (Nyssa sylvatica) and swamp privet (Forestiera acuminata). Each of these bottomland species were differentiated in the unclassified TM image of the reservoir site. Upland hardwoods were uncommon, and appeared as unclassified signatures in the TM scene

The ratioed two-band aerial scans revealed five bottomland species, including southern red oaks (Q. falcata), select white oaks (Q. alba), cottonwood and swamp privet (Foresteria acuminata), water oak (Q. nigra) and willow oak (Quercus phellos).

Interpretation of the November, 1984 NHAP color IR photography failed to distinguish spectral differences among the bottomland tree species. However, deciduous trees entering a period of dormancy could be separated from live oak (Quercus virginiana), magnolia (M. grandiflora) and other evergreens by noting texture and color saturation, resulting in two broad bottomland classifications from the manual photo-interpretation process.

The visual separation of alluvial from flooded hardwoods appeared to be influenced by season of the year and rainfall as well as by the recording medium. Rainfall for the two month period preceding the acquisition of color IR photography interpreted by the USFWS was 4.06 inches (Nov. and Dec., 1980), compared to 12.25 inches (Oct. and Nov., 1986) prior to the videographic low altitude scanning missions. Video imagery produced in the near infrared portion of the spectrum (970 nanometer band) provided clear separation of flooded from alluvial bottomland areas.

Rainfall was at the lowest level in eight years - 3.86 inches for the two month period prior to the May, 1984 Landsat mission used for establishing land cover baseline data.

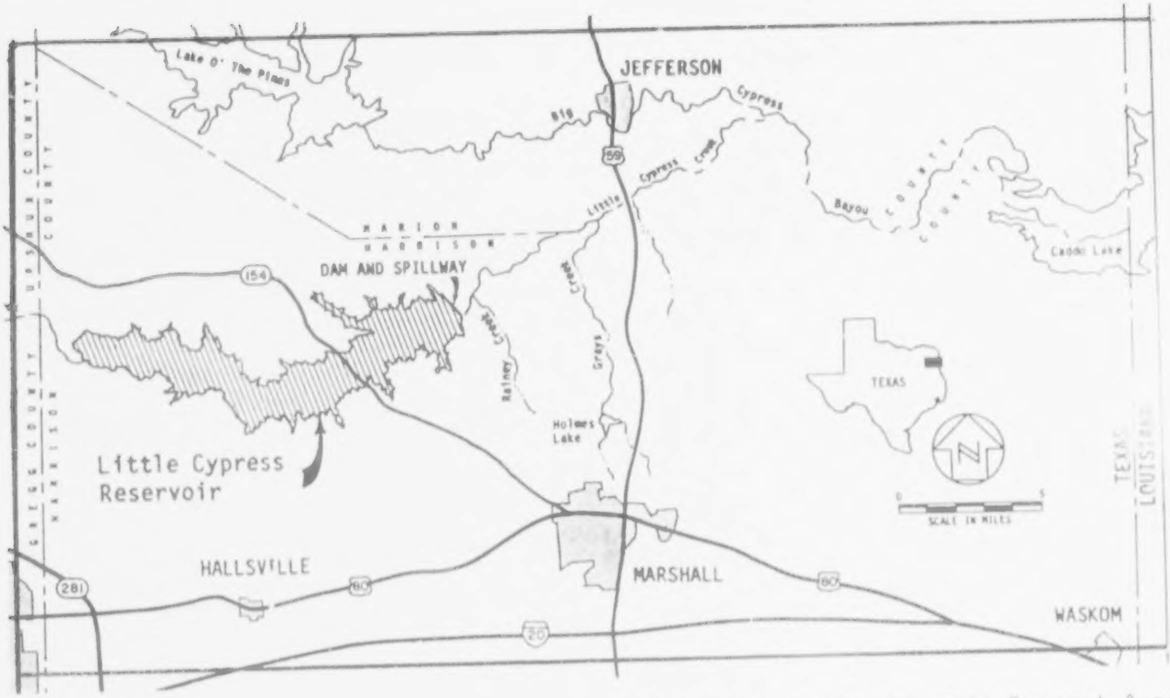

Lake O' The Pines
JEFFERSON
Big
Cypress
Bayou
Little Cypress Creek
59
MARION
HARRISON
UPSHUR COUNTY
GREGG COUNTY
HARRISON COUNTY
154
DAM AND SPILLWAY
Rainey Creek
Grays Creek
Holmes Lake
TEXAS
Caddo Lake
Little Cypress Reservoir
N
0
5
SCALE IN MILES
TEXAS
LOUISIANA
HALLSVILLE
281
80
MARSHALL
80
20
WASKOM

FIGURE 1. Little Cypress Project Area

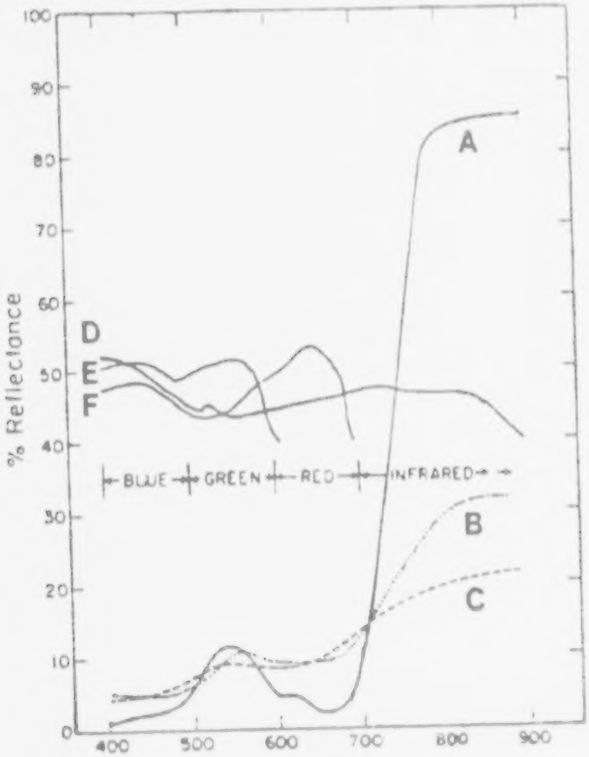


FIGURE 2. Spectral reflectance curves for: A = grass; B = pine trees; C = green paint; D, E, F = cyan, yellow and magenta dye forming layers of Aerochrome Infrared film, Type 2443.

PROPERTIES OF AERIAL INFRARED

Infrared aerial photography is primarily useful in enhancing the color and contrast differences in the terrain. Bodies of water are rendered very dark in sharp contrast to the land, assuming the day is clear. Wet soils appear a mottled dark. Fields and wooded areas are rendered lighter, depending on the amount of foliage or biomass present.

Coniferous and deciduous growth is differentiated, the former appearing darker than the latter during the spring and summer months; with the reverse occuring during late fall and winter dormancy.

The unique property of differential spectral reflection and penetration of leaves has led to the widespread use of aerial infrared for habitat mapping. The energy distribution of atmospheric sunlight peaks at 540 nm, in the green portion of the elctromagnetic spectrum where the sensitivity of the human eye and the average green reflectance of chlorophyll have similar peaks. However infrared reflectances of various leaves, grasses and herbaceous cover differ, with the degree of infrared reflection not related to surface color.

A maximum of 11 land cover classes were discerned by photo-interpretation of the wintertime NHAP and high altitude color infrared photography used for three of the five Little Cypress land cover investigations over the past decade. (Espey, Huston & Associates, 1986; Freese & Nichols, 1986; USFWS, 1980).

Since Aerial Ektachrome film is sensitive to the infrared, and records it as red, healthy foliage and grasses appear predominantly red. However, the broad spectral sensitive of the film, particularly in the cyan dye forming layers (curve D in Figure 2) fails to distinguish the differences in reflectances between 650 and 850 nanometers, which is known as the critical 'red edge' of the spectral response of foliage.

It is in the analysis of the red edge that deciduous hardwood tree species can be differentiated during the early spring or late fall. It was not surprising, therefore to find that the NHAP and high altitude color infrared photography used for color IR mapping of the Little Cypress masked the differences between bottomland hardwood species. Photo-interpretation resulted in the grouping of hardwood species into the two broad classes "deciduous" and "evergreen"."

For the purposes of understanding the hardwood composition of the Little Cypress bayou, it was determined to utilize digital aircraft and satellite imagery which could provide spectral separation and an accurate quantitative inventory of bottomland hardwoods in the Little Cypress basin.

The TM data set used for the investigation had been recorded on May 21, 1984 (Scene ID Y5008916175X0) and coincided with Path 25, Row 37 of the Landsat Worldwide Reference System. One quadrant of the Landsat 5 scene was processed, covering an area encompassing the Little Cypress drainage basin of approximately 84,000 acres out of a quadrant of 132,000 acres.

The scene was relatively cloud free (less than one percent cloud cover over the study area.)

Previous studies analyzing multi-temporal digital data sets, conducted at both NASA's Earth Resources Laboratory at NSTL, Miss., and at the USDA Remote Sensing Center, Weslaco, Tx., concluded that a combination of MSS bands 5 (0.6-0.7 micrometer) and 7 (0.8-1.1 micrometer) provided the best overall correct classification of tree foliage (Stoner, et. al., 1981; Hill; 1985; Everitt, et. al., 1986).

Therefore, to maximize differences in canopy appearance (phenotype) and to provide a common data base for Landsat and aerial scan comparisons, TM bands which most closely approximated the two-band MSS set were chosen for processing (TM bands 3,4 and 5).

DIGITAL DATA ACQUISITION

For the aerial scanning missions, spectral separation of the toe and shoulder of the critical "red edge" response curve, between 660 and 970 nanometers, was achieved by placing narrow-band interference filters (10 nanometer bandwidths) between the rear element of the camera lens and CCD sensors.

The high resolution pictures which were generated with the solid state camera system consisted of 365,000 picture elements (754 horizontal x 488 vertical pixels). A minimum of 450 horizontal TV lines were maintained throughout image processing. The processed CCD images provided spectral information necessary to identify tree species and understory, midstory and overstory components of the forest. The two-meter spatial resolution also made it possible to identify brush berms, the structure of dead trees, shelterbelts and forest edge data needed for habitat evaluations.

By utilizing interference filters on the CCD cameras with similar band widths to TM channels 3, 4, and 5, the CCD imagery could also be used to sub-divide the 30-meter satellite TM images without sacrificing the spectral richness of multi-spectral scanner data which is characteristic of land cover maps produced by NASA-based technology, but at substantially less cost.

Scanning with the solid state vide cameras was carried out in three stages as weather permitted between November 11 and December 7, 1986. Three mapping segments, each approximately 20 miles long and ten miles wide, were flown on east-west headings, using road intersections, transmission lines and impoundments as pilotage reference points. Radio navigation from VORTAC or ADF transmitters did not provide adequate offset to maintain true course headings during wind shifts.

More useful flight guidance was achieved with mobile transceivers which were moved during the mapping runs to each end of the flight line. Transceiver positions were pre-marked in one-third mile increments, using yellow and red spray paint to place crosses on the road shoulder at each end of the flight lines. Ground crews moved from one pre-marked location to another as the aircraft moved away on the mapping runs.

Control of camera motion was achieved by mounting the CCD cameras in a motion-compensating, azimuth controlled mount in the camera hatch of a modified Cessna 206 aircraft. By locking the CCD cameras on nadir ground points during the 33 millisecond video exposure times, "frozen frame" imagery was achieved, effectively eliminating camera motion. Ground resolution of two meters was achieved with this system (Hazard, 1986).

Approximately 500 linear flight line miles were flown at 4,800 ft. altitude (AGL), yielding 3,500 video frames with ground coverage of one-third mile per frame. Nominal forward lap of 10 percent and sidelap of 15 percent were maintained for the most part during the mapping runs, although wind shifts, navigational and occasional power supply problems accounted for a loss of useful imagery, resulting in a completion rate of 86 percent.

Images were recorded serially in the air on an M-format videotape, retrieved in the Ward and Associates image processing laboratory by a CAI-1600 "frame grabber," digitized and downloaded onto a hard disc for processing with Earth Resources Laboratory Application Software (ELAS).

IMAGE PROCESSING

Hardwood species were differentiated by overlaying and ratioing the video data sets. The overlaying processes consisted of mapping the coordinate system of one video frame into the coordinate system of the other. Ratioing, which expanded the gray scale densities associated with the different ground cover reflectances, consisted of division of the 970nm by 650nm data.

The overlay was accomplished with the ELAS module OVLA, requiring the visual identification on the CRT of as many common map control points as possible, such as singular trees, intersections of brush berms, etc., that could be located and plotted in the videographic pairs. Classification of tree species was carried out with with SRCH and MAXL classification software, utilizing a three-pixel sliding window to establish training sets. The ELAS routine SRCH produces statistical signatures for use by MAXL. The data are then classified on the basis of maximum liklihood ratio and Bayesian decision rules. Each pixel is assigned to the class where the statistics of that class best fit the irradiance values of that pixel.

The seven hardwood species were color coded in the composite, ratioed videographic frames and differentiated according to degree of senescence, indicated by infrared reflectance in the 970nm band.

In addition to identifying tree species, spectral analyses also revealed the location of logged over areas, herbaceous cover, dead tree signatures, marshes and several grassland species.

The digital video imagery also provided shadow data for estimating tree height, canopy density, forest edge identification and other spatial variables needed for habitat analyses.

ACCURACY ASSESSMENTS

Geometric correction of the satellite imagery yielded root mean square error (RMSE) values of between two or three pixels (six to nine meters) from map control points, indicating that the aircraft video frames could be located on the satellite imagery with a fair degree of accuracy.

An area of the satellite image designated as the New Diana test site was chosen for field survey after classification analysis indicated that all of the terrestrial and aquatic classes of interest were located in the half mile square area. Field surveys were caried out in April, 1987.

The approximate location of the New Diana site was determined by comparing latitude-longitude coordinates obtained from the flight map, USGS 7 1/2 minute quadrangle mosaic on which the aircraft mapping runs had been drawn. A polygon which identified the location of the New Diana video frame for field inspection was then transposed onto the coordinate system of the TM scene. Site visits to obtain calibration data were made in May, 1987, after foliage was fully developed. The May data set corresponded approximately to the time of the year that the TM scene was obtained.

The results of the field classifications indicated that the springtime TM scene did not fully separate the spectral signatures of the conifer communities. This deficiency was not as apparent in the November videographic data set, which provided a clear gray scale separation of loblolly and short leaf pine associations. The satellite scene provided 12 grass and herbaceous cover classifications, whereas the videographic composites yielded only three of these ground cover classes.

A comparison of the major land cover classes obtained from the composite videographic frames with TM classifications is shown in Table 1.

TABLE 1. ACCURACY ASSESSMENT

	Aircraft/Site Data		TM-5 Data	
Land Cover	Acres	Percent	Acres	Percent
Open water	2.8	5.3	-0-	-0-
Flooded hardwoods	6.2	11.7	7.7	14.6
Alluvial hardwoods				
- Red oak	.4	8.4	1.1	8.5
- Other	4.1	23.8	10.2	13.1
Upland hardwoods	4.9	9.2	[illegible]	9.0
Mixed hardwood/pine	6.2	11.7	[illegible]	16.1
Riparian	2.8	5.3	3.2	6.4
Grasses	8.5	16.1	7.6	14.4
Pure pine	7.0	13.3	6.0	12.3
Disturbed	1.9	3.5	3.5	6.6
TOTALS	52.8	99.9	52.3	100.0

Overall agreement between the two distributions is 80 percent. By disregarding the "disturbed" category, the agreement is 84 percent. The 3.1 percentage difference in the disturbed classification is due to the placement of unclassified pixels into the disturbed category during image processing.

An analysis of variance of the New Diana and TM land cover shows that differences between the two distributions are not significantly different at the .70 probability level, as follows:

			F	dfn	dfd	TotSS
Number	8	8				
Mean	5.0375	5.55	.1558	1	14	95.45
Med	5.55	6.45				
SD	2.343	2.828	TRMT SS		Error SS	
Variance	5.488	7.997	1.051		94.40	

P = .699

It is not surprising to find that the aerial scanning differentiated wetland hardwood speciwes such as cypress, willow oak and water tupelo, whereas the springlike Landsat scene eprovided upland, riparian and alluvial species separation during early leaf-out. The aerial scanning with two meter spatial resolution also provided statistics for HEP variables that were not observable in the color IR photography.

MULTI-SPECTRAL - COLOR IR COMPARISONS

To compare the results of digital imaging with color infrared interpretation, the digital satellite and aircraft data were first reduced from 90 and 22 categories, respectively, into the 11 land cover classes utilized by the USFWS from interpretation of infrared photography (Table 2). The 11 classes were then combined into three major groupings (Table 3), revealing differences in hardwood percentages.

The reduction in the number of spectral classes observable in the TM imagery was achieved by reference to NHAP photography.

Classification of the nearly 4,000 multi-spectral frames obtained by the low altitude scanning was carried out by cross-classification of the 650 and 970 nanometer bands in two-space plots (Hill, 1985).

Mixed and upland hardwoods shared identical signatures in the two space plots, and were therefore separated for classification purposes according to topographic location above and below the 230' contour elevation.

Inspection of Table 3 reveals that the three studies produced by consultants (Wald, Espey- Huston and Freese-Nichols) differed by not more than 2.4 percentage points in estimates of bottomland hardwood acreages, whereas the USFWS overestimated hardwoods by 20.4 percentage points (calculated from the average of the three engineering studies).

TABLE 2: Multi-spectral and Color IR Land Cover Distributions

Land Cover	Number of Signatures	Waid Digital Acres	Waid Digital Percent	USFWS Color IR Acres	USFWS Color IR Percent
Aquatic	3	115	<.01	138	1.0
Cut-over	0	1075	7.7	275	2.0
Grasslands	22	2507	18.0	2064*	15.0
Alluvial Hardwoods	5	4067	29.1	9907	72.0
Upland Hardwoods	(5)	109	<.01	0	0
Marshes	1	16	<.01	0	0
Flooded Hardwoods	6	3103	22.2	138	1.0
Mixed Forest	--	1996	14.3	1100	8.0
Pine Forest	6	407	2.9	138	1.0
Riparian	7	189	1.4	*	--
Disturbed	8	382	2.7	0	<1.0
	60	13966	100.0%	13760	100.0%

F = 1.06 P=.38

*=combined classes

Table 3 displays differences between the digital and USFWS land cover distributions, along with a comparison of the classifications of other vegetative maps of the Little Cypress bayou.

TABLE 3. Acreage Estimates for Combined Classes
Little Cypress Reservoir Site

Major Classes	Waid Digital Acres	Waid Digital %	Espey-Huston Acres	Espey-Huston %	Freese/ Nichols Acres	Freese/ Nichols %	Parks & Wildlife Acres	Parks & Wildlife %	Fish & Wildlife Acres	Fish & Wildlife %
Bottomland Hardwoods	7,170	51.3	7,502	53.7	7,366	52.8	8,239	59.0	10,196	73.0
Mixed Hardwood/ Pine Forests	1,996	14.3	2,028	14.5	3,641	26.1	2,491	17.8	1,116	8.0
Other	4,800	34.4	4,436	31.8	2,959	21.1	3,236	23.2	2,654	19.0
	13,966	100.0	13,966	100.0	13,966	100.0	13,966	100.0	13,966	100.0

* Normalized to 13,966 acres at 230' elevation, MSL.

The Texas Parks and Wildlife Department bottomland hardwood acreage estimates are reported as 59 percent, which is 7.4 percentage points higher than the Waid estimate. Due to the comparability in image processing technology used by TPWD and Waid, the differences between the two estimates is most likely due to selective hardwood logging in the bayou between 1974 and 1984, when the two satellite scenes were obtained.

A one-way analysis of variance of the five distributions fails to reject the hypothesis of no difference in land cover rankings, suggesting that the less costly satellite image processing is the method of choice for land cover analyses when no more than 11 terrestrial cover delineations are needed.

The photo-interpretation methods used for analysis of color infrared photography, and the experience level of the interpreter apparently had important effects on the accuracy of the results. Statistically significant differences occured between the three land cover maps created by photo-interpretation of color infrared photography.

STRUCTURING HABITAT SUITABILITY FROM VIDEOGRAPHIC DATA

To explore the potential use of aircraft video scanning as a source of data needed for HEP and HMEM procedures, multispectral data obtained in the the November flyovers were reproduced by a videoprint process and evaluated for spatial and spectral adequacy.

The evaluation consisted of determining whether or not photo-interpretation of the video prints would provide useful quantitative data on the following wildlife habitat parameters: (1) height of overstory tree canopies, (2) average diameter at breast height of mast producers, (3) percent of tree canopy closure, (4) percent of tree canopy closure of mast producers, and (5) average length of continuous forest edges.

These important habitat suitability variables are among 17 land regimes eight water regimes that provide habitat for wildlife in the area, as described in "Terrestrial Habitat Evaluation Criteria Handbook, Big Sandy Creek, Texas, 1980," developed by the USFWS and the U.S. Corps of Engineers, Fort Worth District.

These variables identify some of the area habitat conditions used in the construction of a Habitat Suitability Index (HSI), as follows:

$$\text{HSI} = \frac{\text{Study Area Habitat Conditions}}{\text{Optimal Habitat Conditions}}$$

This index value, which ranges from 0 to 1, is utilized by the USFWS to calculate acreages deemed necessary to compensate for the removal of bottomland hardwood forests for reservoir purposes.

A HEP analysis is structured around the calculation of habitat units (HU's) for each wildlife species in the area to be impacted. The number of HU's is defined as the product of the Habitat Suitability Index (quality) and the total area of available habitat (quantity).

READEX FICHE best copy available

The quality of the habitat is defined as how well available biomass meets certain life requisites of the resident wildlife species. Life requisites are generally taken to mean food, nesting habitats and security.

The land cover variables needed to satisfy these wildlife requirements are known from biological literature and are expressed as values in HSI "models" for each species.

The detailed measurement of terrestrial variables called for in the HSI models traditionally consumes three days of field survey work for each cover type. In a typical application, field inspection of seven terrestrial cover classificatıcns for 20 wildlife species consumes approximately months of field survey work with a two or three person crew.

The field survey data needed to calibrate a vegetative map produced by digital remote sensing technology (satellite imagery and videographic underflights) can be obtained in one day. Calibration consists of obtaining spectral signatures of land cover species of interest, using a data logging spectroradiometer.

The compilation of land cover data by image processing, and the transfer of this information into HEP format should average from one to two weeks per proposed management action, as compared to three weeks usually required for pre-field planning and interpretation of NHAP infrared photography, site surveys and manual data entry of HEP forms.

The following interpretation of videographic data for the Little Cypress project provides an example of the application of remote sensing technology for habitat suitability measurement.

1. Crown Diameter Measurements

Crown diameter measurements were obtained by placing a randomized dot grid over the 8" X 10" video enlargements and measuring the diameter of each tree canopy appearing under a dot, using a clear plastic ruler divided into 1/32" segments.

The scale of the video imagery, 1 " = 150', and a picture element (pixel) size of two meters permitted classifications of tree canopies into functional space of 4.5 feet square and larger. For the purpose of HEP calculations, tallies were compiles in four crown diameter classes as follows:

1/32" = 4.5' diameter
1/16" = 9.12' diameter
1/8" = 18.25' diameter
1/4" = 36.5' diameter

The crown diameters determined in this manner suggest that USFWS calculations which were based on ground level obser.ations overestimated canopy width.

In the first place, only that portion of the crown which is visible from directly above was measured on the videoprint photographs. Branches cloaked by other trees were not seen, and thin, narrow branches were not resolved in the video raster image, and were, therefore, generally smaller than ground level measurements of the same tree. However, the aerial views can be measured more accurately and provide an evaluation of the functional growing space occupied by a tree. Aerial classifications have been shown to be closely correlated with tree and stand volume (Hagan and Smith, 1986).

2. Determination of Tree Overstory Heights

By photo-interpretation, the length of a tree's shadow can be used to calculate overstory height under the following conditions:

a. The tree is assumed to be vertical
b. Shadows are observable on open, level ground where they are undistorted and easily measured
c. Measured shadows are cast from true tips of the trees rather than from the sides of the canopy
d. The sun's elevation is accurately known for the time of the flight (nearest hour)
e. Latitude and longitude of the site, in minutes and seconds, are known
f. The exact scale of the photography is known (calculated from altitude (AGL) of the aircraft and focal length of the lenses

The angular elevation of the sun for each video frame was determined from the equation:

$$\text{Sin "a"} = (\cos x)(\cos y)(\cos z) + (\sin x)(\sin y)$$

where

Angle x = The sun's declination of latitude on the day of photography, corrected to Greenwich Civil Time, and read from a solar ephemeris

Angle y = The latitude of the geographic point appearing in the center of the videographic frame under analysis

Angle z = The hour angle, or the difference in longitude between the position of the sun and the locality of the site

For example, for images obtained at 2:00 p.m. on December 2, 1986, the calculation of tree height was determined as follows:

$$\text{Tree height} = \text{Shadow length} \times \tan(a) =$$
$$[(10.5\ \text{in})(163\ \text{ft/in}) \times (8.0\ \text{in})] \times (163\ \text{ft/in})/43560\ \text{ft2/acre}$$

Overall results of the analysis show the mean height of bottomland hardwoods on the forest edges to be 47.6 ft in comparison to an estimate of 66.3 ft by the USFWS, based on field surveys in which hypsometers and visual sightings were carried out by the field survey team.

3. Crown Closure

Point sampling of crown closure was carried out with transparent dot-grid overlays consisting of 16 dots per square inch. The proportion of the total number of dots falling on tree crowns gave the meaasure of crown density along a 10-inch block of frame segments in the video enlargements.

The effect of shadows on estimates of crown closure is to cloak minor openings, making the stand appear to be more dense than it actually is. Canopy shadows registered as black in rthe 970nm video frames, making it difficult tp separate shadow openings from midstory crowns. The rule of thumb used (Spurr, 1960) was to assume that the shaded portion of a tree is equal in size to the lighted portion and that the shadow beyond this area lies over an opening or exposed ground.

To verify the accuracy of this manual scoring procedure, a ratioed, overlaid image of two video bands (650 and 970 nanometers) was of the New Diana test site and compared to the video prints used for canopy scoring. The ratioing procedure used to reveal the shadow pockets is as follows:

$$\frac{\text{Visible band} - \text{near-IR band}}{\text{Visible band} + \text{near-IR band}}$$

A comparison of the ratioed image with the single channel video enlargements suggested that large shadows within a stand are indicative of canopy openings, and that small shadows are correlated with irregular tree heights. Photo-interpretation carried out without this initial determination tended to overestimate the density of tree stands in the test site.

The overall density of tree canopy closure was found to be 46.5 percent by photo-interpretation, as compared to an estimate of 92.3 percent by the USFWS survey team which utilized a spherical densitometer for the field work. Estimates of tree canopy closure of mast (acorn) producers (trees of 12-inch DBH or greater) are 25 percent and 94 percent, respectively. The comparison suggests that field sampling and measurement errors biased the USFWS toward overestimation of the age and size of trees in the bottomlands.

4. Diameter at Breast Height

The relationship between diameter at breast height (DBH) and the photo measurable variable of crown diameter in southern forests is well documented (Minor, 1951). The relationship approaches a straight line but is slightly curvilinear or sigmoid in shape, based on a simple linear regression model with a coefficient of determination of 0.76. Similar results were reported by Spurr (1960) who demonstrated a relationship of visible crown diameter and total height to stem diameter, as shown in Figure 3.

The estimate of DBH from photographic measurements is precise only within approximately two inches, using the rule of thumb that stem diameter in inches is approximately equal to one-half of the crown diameter in feet, plus five inches.

Estimates of DBH of overstory trees in the proposed Little Cypress reservoir site derived by application of these curves show a mean DBH of 12.9 inches, as compared to USFWS estimates of 14.4 inches. Validation of field survey shows the photo-interpretation solution to DBH measurements are accurate within one inch 60 percent of the time, and within two inches 86 percent of the time (Aldred and Sayn-Wittgenstein, 1972).

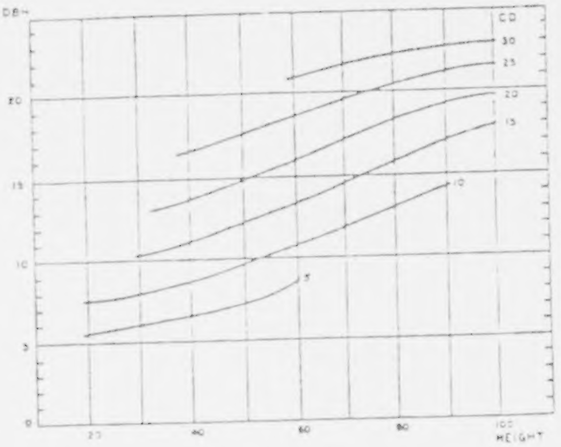


FIGURE 4 Relationship of visible crown diameter and total height to stem diameter for eastern white pine

SUMMARY

A comparison of five videographic and field survey measurements useful for constructing HSI indices for the Little Cypress reservoir site are shown in summary Table 4. Variance between the videographic measurements, constructed by photo interpretation, and projections based on a limited field survey of 57 sample sites, suggest that videographic data provide a somewhat more conservative determination of the size and age of bottomland trees which HEP would designate for "in kind" replacement as a result of inundation of the reservoir site.

TABLE 4. Comparison of Habitat Measurements
for Habitat Suitability Indices

		Videographic Measurements*	Field Survey Estimates**
Height Overstory Trees	>66'	6%	64%
	45' - 66'	62%	36%
	24' - 44'	26%	0
	<24'	6%	0
	Mean (x)	47.6'	66.3'
Percent of Tree Canopy Closure of Mast Producers		25%	94%
Percent of Overall Tree Canopy Closure		46.5%	92.3%
Average Size of Continuous Forested Stand (Acreage)		45.4 ac	62.3 ac
Average Diameter at Breast Height (DBH) of Overstory Trees		12.9'	14.4'

* Based on stratified sample of 352 frames of low altitude videography
** Based on field sample of 57 sites (March 31 - Apr. 3, 1986)

CONCLUSIONS

This report consists of land cover tabulations for the Little Cypress bayou covering 78,094 acres, based on an analysis of May, 1984 Landsat-5 Thematic Mapper imagery, calibrated by low altitude aerial mapping with video scanners in November and December, 1986.

The overall variance among estimates of major land cover classes in the Little Cypress bayou are not significantly different, regardless of whether or not the analyses were based on satellite image processing, photo-interpretation of high altitude photography, or high resolution videographic mapping.

Due to spectral discrimination capability and geographic coverage, satellite image processing potentially provides the most ecomomical means available for locating acreage suitable for trade-off and mitigation purposes in large areas.

Neither digital satellite imagery nor high altitude color infrared photography are adequate for providing data needed for USFWS habitat suitability or habitat management studies due to inadequate spatial resolution (satellite data) or inadequate vegetative separation (color IR).

Photo-interpretation of composite videographic prints, produced by ratioing spectral bands of red and near infrared, provide the spectral and two-meter spatial data needed for habitat suitability construction as part of the HEP process. Rapd and accurate compilation of food, reproductive and security components of habitat suitability indices (HSI) are achieved.

Spectral analyses differentiated tree, herbaceous cover and grassland species needed for food; whereas spatial measurements documented habitat variables related to reproduction and security.

Video mapping can reduce the cost of field work for HEP and HMEM evaluations by one-half, and the cost of land cover analysis for mitigation negotiations by approximately one-fourth.

Disadvantages of the present state of videographic technology is reliance on the use of optical overlays on a CRT screen or videoprint, such as dot grids, plastic rulers and other transparent scalers to measure distances between ground cover and canopy densities. With advances in photogrammetry, particularly the development of analytic stereo-compilers in 35/70mm format which accept digital input, and software which can interpret three dimensional drawings, the photogrammetric technology is available to overcome these disadvantages.

By recording videographic data in stereo format with 60 percent forward overlap, is is possible to use new small format stereo compilers to scale the individual frames with x, y and z coordinates, therby increasing the applicability of videographic mapping for terrestrial and aquatic measurements. Both spectral and spatial measurements can be computed, thereby increasing the speed and accuracy of land cover assessments based on videographic technology.

REFERENCES

CLOUD, T., "Interagency Planning Report in Regard to the Little Cypress Utility District Application. "U.S. Fish & Wildlife Service, 1980.

CONNORS, P., BRANNON, D., "Technical Exchange Agreement between the National Aeronautics and Space Administration and Earthscan, Inc.,in the Area of Remote Sensing Technology Development," Earth Resources Laboratory, NSTL, Ms., 1986.

ESPEY-HUSTON & ASSOCIATES, INC., "Little Cypress Bayou Habitat Map,"Austin, Tx., 1986.

EVERITT, J.H.; RICHARDSON, A.J.; NIXON, P.R.; "Canopy Reflectance Characteristics of Succulent and Nonsucculent Rangeland Plant Species," Photogrammetric Engineering and Remote Sensing, Vol. 52, No. 12, 1986.

FREESE & NICHOLS, INC., "Little Cypress Reservoir Effects of Water Quality and Fish and Wildlife," Fort Woprth, Tx., 1986.

FRYE, R.,"Tabulations of Cover Types to be Impacted by the Normal Pool Level of the Proposed Little Cypress Reservoir," Texas Parks & Wildlife Dept., Austin, Tx. 1986.

GRAHAM, M.H.; JUNKIN, B.G.; KALCIS, M.T.; PEARSON, R.W.; and SEYFARTH, B.R., "Earth Resources Application Software - Vol. II (User Reference)," Earth Resources Laboratory, NSTL, Ms., 1985.

HAGAN, G.F.; SMITH, J.L., "Prediction of Tree Groundline Diameter from Crown Measurements Made on 35-mm Aerial Photography, Photogrammetric Engineering and Remote Sensing, LII (5), pp 687-690, May, 1986.

HARLE, J., "Preliminary Engineering Report for the Little Cypress Reservoir," Kindle, Stone & Associates, Inc., Longview, Tx., 1986.

HAZARD, W.R., "Experiments with Video Stereography for Contour Mapping," Video Technology Newsletter, Issue No. 5, American Society of Photogrammetry & Remote Sensing, Falls Church, Va., 1985.

HILL, C.L., "Ducks Unlimited Joint Research Project, Report No. 238," National Space Technology Laboratories, Earth Resources Laboratory, NSTL, Ms., 1985.

________________"Timber Resources Inventory and Monitoring Joint Research Project," NASA/NSTL/ERL Report No. 237, NSTL, Ms., 1985.

JOHNSON, J.L., "Wildlife Planning Transmittal Letter to the District Engineer," Corps of Engineers, U.S. Army, Fort Worth, Tx., 1986.

MINOR, C.O., "Stem-Crown Diameter Relations in Southern Pine," Journal of Forestry, 49(7): pp. 490-493, 1951.

NIXON, P.R.; NAMKENLYN, R.; WEIGAND, C.L., "Spatial and Temperature Variations of Crop Canopy Temperatures and Implications for Irrigation Scheduling, *Remote Sensing of Earth Resources*, Vol. 2, pp 643-657, 1973.

SEVER, T.L., "Feasibility Study to Determine the Utility of Advanced Remote Sensing Technology in Archeological Investigations," NASA/NSTL/ERL Report No. 227, NSTL, Ms., 1983.

SPURR, S.H., *Photogrammetry and Photo-Interpretation*, 2nd Ed., Ronald Press, New York, N.Y., 1960.

STONER, E.R.; MAY, G.A.; KALCIS, M.T., "Evaluation of Multiband, Multitemporal and Transformed Landsat MSS Data for Land Cover Area Estimation," NASA/NSTL/ERL Report No. 196, NSTL, Ms.,1981.

ESTABLISHING FLOW/AREA RELATIONSHIPS OF RIVERINE GRAVELS
WITH
REMOTELY SENSED IMAGERY

BY
BILL CLEMENT
CARTOGRAPHY AND REMOTE SENSING SECTION

AND
JEFF HEPLER
RESERVOIR REGULATION AND WATER QUALITY SECTION

PORTLAND DISTRICT
U.S. ARMY CORPS OF ENGINEERS

ABSTRACT

Anadromous fisheries are an intensively managed natural resource in the Pacific Northwest. Reservoir regulation operations have a significant impact on anadromous fish spawning habitats. To identify such potential impacts, a pilot project was conducted in which remotely sensed imagery was utilized to identify the location and extent of riverine gravels which would be subject to dewatering during special reservoir regulation operations. The ultimate goal of the operation was to quantify salmon habitat made unavailable by low flows. The advantages and disadvantages of available remote sensing systems and techniques were evaluated and a thermal infrared video output system was chosen. Results indicate that this technique can economically determine dewatered gravel area as a function of reservoir discharge.

METHODOLOGY

A literature search was conducted to discover which remote sensing techniques would be best for this application. Two readily available remote sensing techniques met the feature delineation, resolution, image processing, data storage and economic feasibility requirements: conventional aerial photography and a thermal scanning system.

Aerial photography has many desirable attributes. The use of different film types, in conjunction with various spectral filters, may be used to enhance the appearance of desired surface features. The resolution of aerial photography is well within the accuracy requirements for the project. The output product is in the form of film prints and the areas of exposed gravels may be directly digitized. The prints may be reviewed easily, placed in order on a layout table for an overall view of the project area and viewed in stereo to improve interpretation.

One disadvantage of using aerial photography is that the Corps of Engineers-Portland District office currently does not have the ability to acquire aerial photography in-house. Contracting for this service decreases the flexibility required for the timing of such a project. The flight time and stable river levels must correspond exactly, posing a potential communications problem between the aircraft and reservoir operations personnel. The plane is forced to land or circle overhead while waiting for the river to rise to the required level. After the imagery is collected, color film processing generally requires a turn-around time of one to two weeks, and only then can it be determined if the aerial coverage and film exposure are adequate. If not, the project must be re-flown, with duplicate expenditures for aviation, film, and ground truth personnel.

Most aerial photography must be acquired when light levels are high, which is a problem during the winter months due to low sun angle at the project area (43 degrees north latitude) and extensive cloud cover. Shadows of trees along riverbanks may make edge delineation more difficult. For the above reasons, aerial film imagery is usually acquired between 10 a.m. and 2 p.m. This results in a 4-hour imagery acquisition time period, which is insufficient to fly a long stretch of river at several different flows without resorting to several flying days. The cost of the travel time between the contractor's home airport and the project site will increase commensurately. Aerial photography is not inexpensive. Costs include flying time for a small plane and a trained aerial photography pilot, nine inch negative film, processing and printing.

Once the drawbacks of using aerial film imagery for this particular application were fully realized, an alternate method was investigated. A thermal infrared scanning system had been used previously by the Cartography and Remote Sensing Section for thermal mapping of the debris avalanche on Mt. St. Helens (COE Remote sensing Symposium #5), and it was believed that this sensor might also be used for gravel bar delineation. The thermal imaging system consists of a mercury-cadmium-telluride sensor, cooled by argon gas to -200 degrees celsius. The system senses in the 8 to 12 micrometer region of the electro-magnetic spectrum, and is able to sense temperature differences as small as 0.2 degrees celsius. It has a video output with an E.I.A. RS-170 format for output to a common video cassette recorder. The thermal scanner, mounted on the nose of a small helicopter, records video imagery of surface heat patterns. This imagery is displayed in real time on a video monitor in the helicopter and is simultaneously stored on a 3/4" video tape.

The real time display helps the operator insure that the pilot is covering the areas of interest. It allows the operator to make adjustments to the sensor controls to produce the maximum differentiation between gravel bars, the water surface, and vegetated areas bordering the river channel. The video tape format also insures that the data are immediately available for interpretation. The continuous image on a video tape allows a still picture to be obtained of any scene along the river. The characteristics of thermal surface emissions allow imagery acquisition during day or night, as long as a temperature difference exists between the gravel bars and the surrounding material. Previous experience with this thermal system provided Cartography and Remote Sensing Section personnel with the background information necessary to carry out the project's tasks. The most important consideration in using such a system may be the flexibility inherent in real time image collection under the direct control of Corps project managers.

Disadvantages of thermal infrared for this application include reduced spatial resolution resulting from a video output system (485 TV lines per image), and significant increases in pixel size with increased flying height. Other disadvantages are similar to those associated with aerial photography. During daytime image acquisition, solar thermal influences will contribute to "shadows" on areas of interest. Also, the aircraft must sit idle while the river flows stabilize. Landing requirements for helicopters are much less stringent than those for airplanes, eliminating the need for an airport and reducing travel time and costs. Based on the above considerations, it was decided that a thermal imaging system would best suit the needs of the project.

FLIGHT PLANNING

A number of factors were taken into account when planning for the mission. First, a trade-off existed between the total area contained within one image, the flying height of the aircraft, and the resolution (pixel size). It was necessary to calculate flying height to insure that the areal coverage would be large enough to contain the entire river width, yet produce a pixel size small enough to maintain the desired minimal mapping unit. There was another trade-off between the pixel size and the slope of the gravel bars. If the gravel bars had a shallow slope, a small rise in river levels would show a significant areal change, allowing a larger pixel size. If the slope of the gravel bars were steep, a great rise in river levels would result in a small change in the inundated area, necessitating a smaller pixel size and commensurate reduction in swath width. The forward speed of the helicopter must be slow enough so that the image will not be blurred. The helicopter attitude must be level with no roll or pitch, to assure true verticality of the image. Non-level attitudes will result in uneven image scales.

Weather is an important consideration. A significant temperature difference must exist between the gravel bars and the water and surrounding vegetation. For this test flight, water and ambient air temperatures were monitored prior to the flight to insure that this difference was present.

Thermal radiation is attenuated by water in the atmosphere, so that clouds, fog, or even water vapor can affect image quality. Wind velocity is a factor that will affect the helicopter's ability to maintain a vertical attitude. Scale distortion of the final product will result should the pilot bank the aircraft to compensate for high winds.

The thermal system was leased when the weather forecast seemed to favor mission requirements. Other equipment consisted of a battery-powered 3/4" video cassette recorder, extra video tapes, aerial imagery for orientation, and radios for communication, all of which had to be obtained just prior to the flight. The helicopter obtained possessed a configuration that supported proper mounting and power supply. The system we procured for the flight had an STC (Supplemental Type Certificate) that allowed it to be mounted on the cargo hook of a particular type of helicopter. We were fortunate to find a helicopter company with the right type of helicopter and a mechanic who was familiar with the mounting of the system on the aircraft.

The helicopter pilot took a short while to develop the skills necessary to keep the helicopter flying level at a slow speed while navigating by the thermal infrared monitor to ensure the river stayed within the field of view at all times. In addition, he had to maintain an exact altitude in order to keep the resultant imagery at a consistent scale. The flight was originally planned to be flown at a height of 802 feet above ground, resulting in a 400 foot image swath and a 0.61 square foot pixel size. In-flight evaluation, however, determined that the pilot was unable to hold the river in the monitor field of view. The flying height was subsequently raised to 1604 feet, then again to 3208 feet, resulting in a 1600 foot wide swath with a 9.73 foot square pixel size. Once acceptable imagery was collected, the reservoir discharge was slowly raised to higher flow levels and the river was flown again.

IMAGE PROCESSING

The video tapes were displayed on a professional quality cassette player and freeze-framed when the gravel bar of interest was displayed. The images were then input into the section's image processing system through the use of video digitizing software. Image scale was calculated from flight parameters and the number of rows and columns of the image file were proportioned commensurately. The resulting image was displayed on the RGB monitor. The gravel bar areas were interactively outlined and assigned to an empty class. Statistics were computed on the image file and the number of re-classified pixels were multiplied by the known pixel size to obtain the acreages of exposed gravels. Acreages of the exposed gravels were then plotted against flow as the dependent variable.

CONCLUSION

Analysis indicates that gravel bar areas can be efficiently and accurately determined. Three representative gravel deposits were analyzed, and ground checks indicated that the results could be extrapolated to other nearby gravel deposits. Acreage accuracy has been estimated to be within 10 percent.

DETERMINATION OF CRITICAL EROSION AREAS WITHIN AN URBAN WATERSHED USING LANDSAT TM AND THE UNIVERSAL SOIL LOSS EQUATION

Ken M. Morgan, Rick Sinclair, and David Koger
Center For Remote Sensing
Texas Christian University
Fort Worth, TX

ABSTRACT

Landsat Thematic Mapper (TM) data and the Universal Soil Loss Equation (USLE) were incorporated into a geographic information system (GIS) to determine land use, quantify areawide soil losses, and locate critical erosion sites in the Lake Arlington watershed in North Central Texas. Our remote sensing analysis showed a 41% increase in areawide soil losses in the watershed over a four year period. The increase was primarily due to urban construction sites and long term fallow agricultural land. These critical erosion sites (exceeding 15 t/a/yr) were color-coded and located on the imagery as part of the permanent data base for watershed management by the City of Arlington. Our study demonstrates the usefulness of integrating satellite data with a GIS for the purposes of monitoring land use changes that affect areawide soil losses. When used properly, Landsat TM data can be an integral part of watershed programs concerned with land use and soil loss management.

Introduction

The TCU Center for Remote Sensing and Energy Research in conjunction with the City of Arlington Utilities Department is interested in developing techniques for the acquisition of timely watershed information for many reasons, including: (1) protecting or improving existing water quality, (2) estimating areawide soil losses, and (3) identifying critical areas of erosion.

Land use information within the Lake Arlington watershed in Tarrant County, Texas was determined using Landsat TM satellite data. The Landsat TM satellite measures and records six values of reflected light energy (ranging from blue to mid-infrared) with a ground area of 30 meters by 30 meters (0.2 acres). Each full Landsat scene (100 miles by 100 miles) consists of nearly 40 million of these ground cells also called "pixels" (picture elements), and can be displayed on a CRT. We covered Lake Arlington watershed with three 8 mile by 8 mile TM subscenes to form a mosaic.

The quality, quantity, and timing of watershed runoff is strongly dependent on land use and cover (Soil Conservation Service, 1975). Landsat Multispectral Scanner (MSS) data have been used to identify land use and cover classes relevant to runoff studies (Harvey and Soloman, 1984). Compared to MSS, Landsat TM offers higher spatial resolution (30 meters versus 79 meters) and more spectral bands (six versus four). Thus, TM data should provide greater detail for inventorying land use and cover types.

We have two objectives in this study. One is to use the relatively new Landsat TM to map land use cover within the watershed. The other objective is to develop a GIS to quantify soil losses from the watershed resulting from field erosion using Landsat TM data and the Universal Soil Loss Equation.

WATERSHED SOIL LOSS DETERMINATION

Areawide soil loss from field (sheet and rill) erosion for a watershed is usually calculated using the Universal Soil Loss Equation (USLE):

$$A = R \times K \times LS \times CP$$

A = soil loss (tons per acre per year)
R = rainfall factor
K = soil erosion factor
LS = slope factor
CP = land use factor

The USLE is used widely by the SCS for soil erosion predictions and conservation planning. As can be seen, this equation involves numerous factors relating to the potential for erosion in an area. Values for the factors in the equation are taken from charts and tables published by the SCS (1979). For a watershed, the factors R, K, and LS essentially remain constant. However, C and P may change from year to year as land use changes. Remote sensing procedures can help alleviate the problem of monitoring land use changes by providing up-to-date coverage of entire watersheds (Morgan and Nalepa, 1982). For our study, a GIS was developed to store, merge, and calculate field soil erosion, A, utilizing the USLE and TM data.

DEVELOPMENT OF THE GIS

To conduct this study, we constructed a raster based GIS consisting of 30 meter by 30 meter pixels that geometrically matched our Landsat TM image-mosaic covering the entire watershed. For each of the more than 250,000 pixels, information for the USLE was determined, mapped, and photodigitized into the computer for soil loss calculations. The procedures we followed for obtaining rainfall, soils, topography and land use data are described are described below:

Determination of the Rainfall Factor (R):

The first parameter in the USLE is the rainfall factor, which represents the erosive force for average yearly precipitation and can be determined for anywhere in the U.S. For the Lake Arlington watershed, R, was determined using the isoerodent map found in the Soil Conservation Service Guide to Sedimentation Investigations (1979). This factor is derived from 100 year data and is a constant equal to 285 for the entire watershed. The rainfall factor represents the erosive force for average yearly precipitation.

Soil Erodibility (K) Factor:

K in the USLE relates to the erodibility of the various soils that exist in a watershed. The erodibility of Texas soils have been determined from field and lab studies conducted by the SCS. The factor values for the equation are published in county soil survey reports.

1. A soil group overlay was drafted using SCS Soil Survey maps for the watershed.
2. K values are provided by the Engineering Properties tables obtained from the from the Soil Surveys of Tarrant and Johnson Counties.
3. The soil group overlay was photodigitized (a specialized video camera was used to transform the map of the soil groups overlay into digital form.
4. The photodigitized overlay was "stretch" fitted to our GIS.
5. K factor data values were assigned to corresponding areas within the computerized soil group overlay. The final product consists of soil erosion factor values for each pixel within the watershed. K values ranged from 0.31 - 0.34. The higher the value, the more

erodible the soil.

The Slope (LS) Factor:

Slope length (L) and percent slope (S) are important to sediment transportation. These topographic factors were determined throughout the watershed and utilized in our data base using the following steps:

1. A topographic overlay for the watershed was drafted using USGS topographic maps.
2. The slope gradients (S) and slope lengths (L) were measured from the topographic maps, converted to LS factors given on SCS charts (SCS, 1979).
3. The LS factors were displayed on a color-coded map and photoditigitized into the GIS.

Land Use Classification and Factor (CP):

The type of land use is, of course, important to determining the erosion potential of any area. As shown below, seven land use categories were classified and mapped from the satellite imagery for 1984. Remote sensing land use/cover classification methods were applied according to a previous published report (Phillips et al.,1986).

1. Landsat TM computer compatible tapes (CCTs) for 1984 were obtained for the study area.
2. The coordinates (location) of the Lake Arlington watershed were determined for the Landsat TM tape and all of the bands were fed into the computer.
3. Appropriate "training sets" representing each land use category was selected and field checked for verification.
4. Using the spectral signature data from the imagery for each training set, each pixel within the watershed was compared and classified by the computer.
5. Once the individual land use/cover categories were classified, each was compared to the other in order to eliminate any classification overlap.
6. A final land use/cover map for 1984 was generated for the three subscenes by combining or "stacking" the individual classification files: e.g. Residential file + Commercial file + Rangeland file + etc. = Land use/cover map.
7. USLE factor values (C and P) attributed to these land use categories were entered into the computer for each of the pixels in the watershed.

AREA SOIL LOSS (A) DETERMINATION

At this point, all the necessary data (factor values) for soil loss calculations have been entered in the computer. There are now four primary data sets in our GIS: 1. rainfall data. 2. erosion data. 3. slope data. 4. land use data.

It is important to remember that our watershed contains about 250,000 pixels. Each of these pixels (30 meters by 30 meters) now contains a discrete numerical value for rainfall (R), erosion (K), slope (LS), and land use/cover (CP). The USLE is as follows:

$$A = R \times K \times LS \times CP$$

Thus, area soil loss due to sheet and rill (field) erosion (A) is calculated for each of the pixel locations on the three subscenes in order to generate the final soil loss data set. As a result, a program was designed to satisfy the project requirements of handling over 1 million bits of information and calculating an average value for A over the entire watershed. Our USLE-GIS program is highly flexible and may be applied to any watershed or other specified land area. Figure 1 illustrates how the calculation of soil loss, A, was performed on a pixel-by-pixel basis using our data sets and the computer program.

DISCUSSION OF RESULTS

Values for field erosion, A, in the Lake Arlington watershed were calculated for 1984 using remote sensing techniques for determining land uses (as described earlier in this report). Our Land Use Classification Chart is shown in Table 1. The land use category of most concern is that of construction/fallow. Approximately 15% of the land in the watershed is classified as construction/fallow (bare) soil in 1984. Of course, bare soil conditions can lead to high soil losses.

It was found from our study that 2.5 t/a/yr of soil is being lost due to field erosion. This compares to 1.5 t/a/yr calculated in 1980 by the North Central Texas Council of Governments (NCTCOG) and represents a 41% increase over the last four years. The 2.5 t/a/yr translates to about 228,880 tons of soil per year lost from land (91,520 acres) in the watershed. About 1/3 of this may be getting to the reservoir (SCS, 1979). Critical areas of field erosion (identified as those areas > 15 t/a/yr) were displayed in

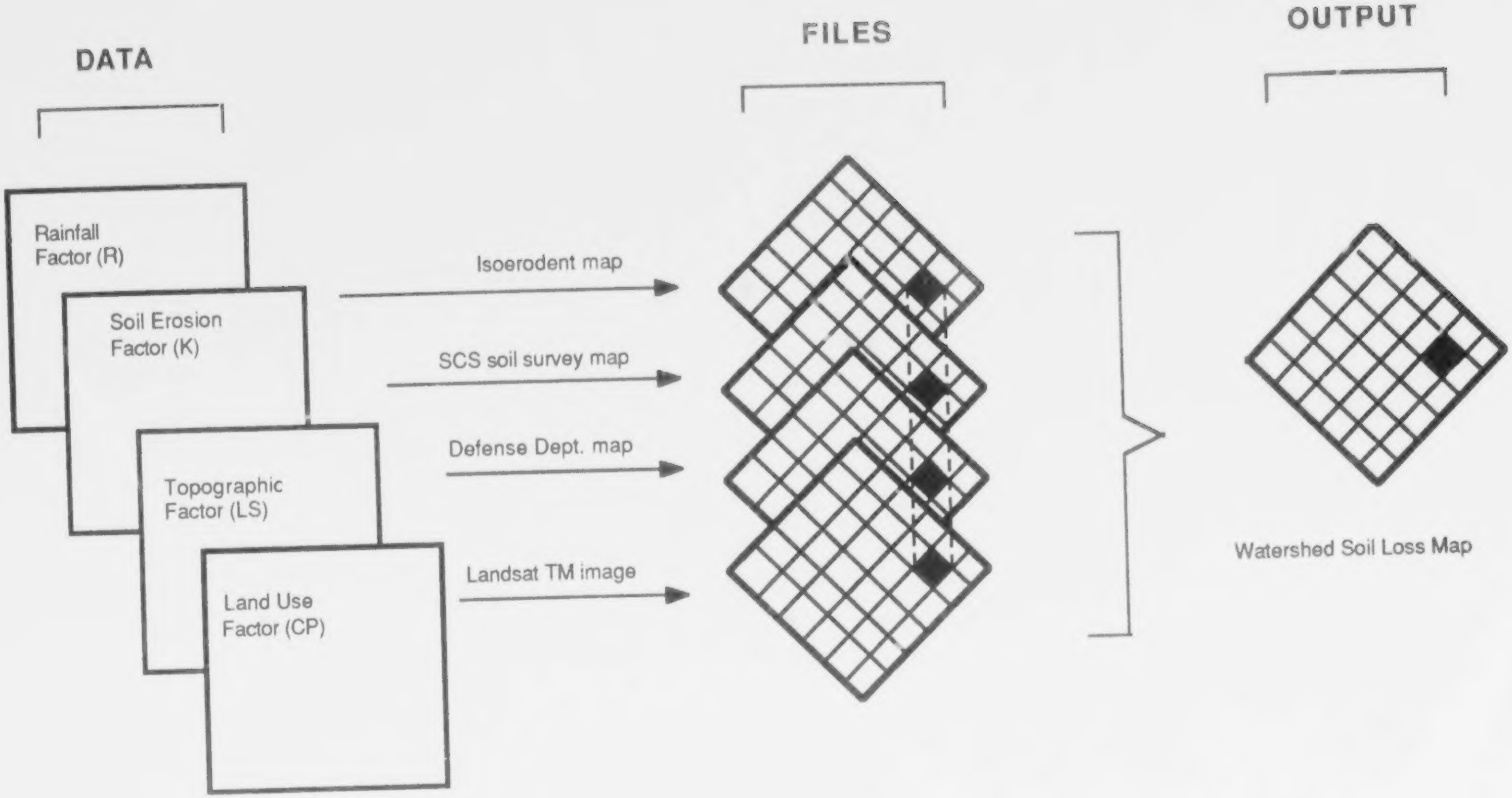

DATA
FILES
OUTPUT
Rainfall Factor (R)
Soil Erosion Factor (K)
Topographic Factor (LS)
Land Use Factor (CP)
Isoerodent map
SCS soil survey map
Defense Dept. map
Landsat TM image
Watershed Soil Loss Map

FIGURE 1. Computer Data Integration of USLE Information for Lake Arlington Watershe

TABLE 1. Land Use Classification For Lake Arlington Watershed Derived From TM Data.

LAND USE & LAND COVER	PERCENT (%) COVERAGE OF WATERSHED
WATER	1.2
RESIDENTIAL	12.6
COMMERCIAL / TRANSPORTATION	8.7
BRUSH / WOODLAND	19.6
CROP / RANGELAND	42.1
RECREATIONAL	0.7
CONSTRUCTION / FALLOW	15.1

(identified as those areas > 15 t/a/yr) were displayed in red as an overlay on our final TM image mosaic. Approximately 5% (4,600 acres) of the watershed experiences an average annual soil loss greater than 15 t/a/yr.

High sediment loading from these critical areas can have terrestrial, aquatic, and economic impacts in a watershed. Valuable agricultural soil is lost, water quality is degraded, and reservoir storage area is lost (Morgan et al., 1978). Plans and policies that encourage better land management practices must be considered and implemented as soon as possible to slow down the soil loss and sedimentation that is occurring in the Lake Arlington watershed (especially those areas identified as critical).

SUMMARY AND CONCLUSIONS

The quality, quantity, and timing of watershed runoff are strongly dependent on land use and cover. Landsat TM and our USLE-GIS proved useful in handling the large volume of data needed to calculate areawide soil losses due to sheet and rill erosion. Traditional time-consuming, labor intensive field work was replaced with satellite imagery, maps, and computer processing. Four data files constitute the land information base including rainfall, soil erodibility, topography, and land use.

The land use was determined from Landsat TM (30 meter) data. These satellite data offer classification accuracy and repeatability so that updated soil loss calculations can be conducted on a routine basis to see if implemented plans are, in fact, reducing erosion.

Specific conclusion drawn from our study are:

1) Landsat TM data can be used for accurate land use mapping.
2) A USLE-GIS can be constructed to store, merge, and calculate areawide soil losses.
3) In our watershed, field erosion increased from 1.5 t/a/yr in 1980 to 2.5 t/a/yr in 1984 (a 41% increase).
4) Approximately 5% of the watershed is experiencing critical erosion losses (> 15 t/a/yr).
5) The major source of critical erosion areas is from construction/fallow (bare soil) areas.

REFERENCES

HARVEY, K.D. and SOLOMON, K.D., "Satellite Remotely-Sensed Land Use Cover Data for Hydrologic Modeling," Canadian Journal of Remote Sensing, Vol. 24-11, 1984, pp. 237-247.

MORGAN, K.M.; LEE, G.B.; KIEFER, R.W.; DANIEL, T.C.; BUBENZER, G.D.; and MURDOCK, J.T., "Prediction of Soil Loss on Cropland with Remote Sensing," J. Soil and Water Conservation, Vol. 33, No. 6, Nov-Dec, 1978, pp. 291-293.

MORGAN K.M.; NALEPA, R., "Application of Aerial Photographic and Computer Analysis to the USLE for Areawide Erosion Studies," J. Soil and Water Conservation, Vol. 37, No. 6, Dec-Nov, 1982, pp. 347-350.

PHILLIPS, K.M.; MORGAN, K.M.; NEWLAND, L.N. and KOGER, D.G., "Thematic Mapper Data: A New Land Planning Tool," J. Soil and Water Conservation, Vol. 41, No. 5, Sept-Oct, 1986, pp 301-303.

SOIL CONSERVATION SERVICE, "Urban Hydrology for Small Watersheds," Technical Release No. 55, USDA, Washington, D.C., 1975, 46p.

SOIL CONSERVATION SERVICE, "Guide to Sedimentation Investigations," Engineering Series No. 701, South Technical Service Center, 1979, 32p.

SESSION V

DEVELOPING A NATURAL RESOURCE INVENTORY AND MANAGEMENT METHODOLOGY A CASE STUDY

Michael R. Waring

Bruce E. Davis

U.S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180-0631

ABSTRACT

An innovative land use planning, inventory and management methodology is under development for Training and Doctrine Command (TRADOC) to use at its installations. The study was initiated in 1983 in response to a Government Accounting Office (GAO) report encouraging installations to develop and maintain Natural Resource Management Plans and address multiple use management principles consistent with the military mission. Multiple use management can be used to enhance and protect training areas by providing sustained training realism through the protection of critical resources (e.g., vegetation or highly erodable soils).

Forests, soils, and wildlife were intensively inventoried for this study. These, together with other data bases on hydrology, endangered species, cultural resources, and training requirements are being analyzed on both a Geographic Information System (GIS) and a data base management system. The goal is to develop an understanding of the complex and often unique interrelationships that occur among the various resources and between those resources and the actual training requirements. Development of a dynamic, rather than static, management plan will enhance responses to changing needs over time and provide the manager with a user-friendly system. This will allow quick analysis and allocation of alternative sites among competing land uses.

Many of the principles used in the development of this methodology are directly applicable to civil works functions. The method has been tested for use in wetlands delineation on the Cache River in Arkansas. Future plans include adapting the methodology to the master planning process and cultural resources management plan development.

INTRODUCTION

The U.S. Army Engineer Waterways Experiment Station (WES) initiated a study in October, 1983 to develop an innovative natural resource inventory and management methodology for TRADOC. The study is partially in response to a Government Accounting Office (GAO) report (1981) recommending installations place greater emphasis on developing and maintaining natural resource management plans and a Department of Defense (DOD) policy requiring multiple use management consistent with the military mission. A second report by Jahn, Cook and Hughes (1984) reiterated these same needs.

Objectives of the study are two-fold: first, to produce a methodology for resource inventory, planning, and management that can be used by TRADOC at other installations, and second, to produce an inventory and allocation plan specifically for the study site. In order to be useful to installation personnel, the methodology must be user friendly, contain a relatively easy to maintain data base, and provide for dynamic, rather than static, resource management allocations.

Fort Benning, Georgia was selected as the study site for developing the methodology based on three main reasons: 1) it has varied and abundant natural resources, 2) it is a center for both infantry and mechanized training, and 3) it has an in-place and functioning Geographic Information System (GIS). The post consists of approximately 182,000 acres, with 16,000 acres in cantonment areas, 33,000 acres in ranges and impact areas, and the remaining 133,000 acres in maneuver training areas. The maneuver areas are the primary focus of this study.

The entire post is divided into compartments that range in size from less than 1,000 acres to over 2,000 acres. They are generally bounded by roads or recognizable streams. Both training and natural resource management is practiced on a compartmental basis.

METHODS AND RESULTS

We identified nine separate tasks for the study:

Task I - Conduct Preliminary Field Investigation
Task II - Review Statutes and Regulations on Land Use
Task III - Review Mission Land Requirements
Task IV - Inventory Natural Resources
Task V - Review Potential Demand for Alternative Land Uses
Task VI - Determine Potential Land Uses
Task VII - Determine Existing Management Objectives
Task VIII - Determine Land Suitability
Task IX - Allocate Resources Among Competing Uses

Many of these tasks, although listed separately, were actually conducted concurrently. The preliminary field investigation was used to further define the problem and determine the extent and nature of existing data bases. We found that although data existed in some areas, much of it was either too general to be of use or needed extensive field work to verify or expand it. Data were available for hydrology, historical/archaeological features, endangered species (needed verification), soils (an Order II soil survey was available for Muscogee County only), some forestry and wildlife parameters, and cross-country mobility.

For Task II, we reviewed all relevant statutes and regulations on land use planning, natural resource management, cultural resource protection, endangered species, and related areas of concern. This review included publications at the Federal, State, and local levels. Overall, we found some conflict in responsibilities and authorities, many of which are currently being examined for change.

Task III, Review of Mission Land Requirements, is one of the most important since training is the primary objective for any military installation. Data were obtained for both mechanized and straight infantry training through a series of interviews with the primary trainers in each unit and with personnel in the Department of Plans and Training (DPT). Historical training records were summarized to determine how and where training was taking place. Initially, we hoped that trainers could identify specific types of terrain and natural resources needed for different training scenarios. However, this did not materialize; in most cases, it appears that the trainers are assigned and use areas regardless of the suitability of the resource for supporting a particular type of training.

Based on information collected in the preliminary investigation, we determined that inventories would be needed for forestry, soils, and wildlife (Task IV). A cooperative research agreement with the U.S. Forest Service was initiated to complete forest data collection started by the Fort Benning staff as part of their on-going management. A modified continuous inventory of stand conditions was used to provide the most detailed information possible on a stand-level basis. Additionally, this agreement provided for the collection of wildlife habitat data for six species: White-tailed Deer (*Odocoileus virginianus*), Bobwhite Quail (*Colinus virginianus*), Eastern Turkey (*Meleagris gallopavo*), Eastern Gray Squirrel (*Sciurus carolinensis*), Wood Duck (*Aix sponsa*), and the Red-Cockaded Woodpecker (*Picoides borealis*).

Soils information was also found to be lacking, with only one third of the post (Muscogee County) completed. Through an agreement with the U.S. Department of Agriculture Soil Conservation Service, Order II soil surveys were completed for the remainder of the post in Georgia (Chattahoochee County, 80,000 acres) and Alabama (part of Russell County, 12,000 acres). Soil types were delineated on a scale of 1:25000 to coincide with available military maps. Additional soils information from the "Fort Benning, Georgia Terrain Analysis" (1976) were also included in the data input.

Under Tasks V and VI, we examined the potential demand for alternative, non-mission related uses of installation lands and then compared these to the resource data and military mission for compatibility. Special emphasis was given to potential revenue generating land uses such as agricultural leasing, recreation, and alternative forest products. In general, we found that current practices seem to be the best for the situation. Little demand exists for row crop production and agricultural leases (hay, grazing) are generally not compatible with the military mission. Revenues could, however, be generated through a restructuring of current policies regarding hunting and fishing.

Goals, objectives, and management requirements at all levels in the chain of command were examined in Task VII. Restrictions from use based on safety and security considerations were noted. Also, economic (timber production, etc.), aesthetic, environmental (endangered species, erosion control, etc.), and morale support goals and objectives were examined. In many cases, clearly delineated goals and objectives were not written but were understood in very broad terms.

Based on management objectives, mission land requirements, potential land uses, and resource inventories, a series of land suitability maps are being constructed in Task VIII. Natural resource suitability maps provide an indication of what a particular compartment may be suitable for, based on the complex interaction of such factors as site index, hydrology, existing forest type, and the location and abundance of sensitive areas (endangered species colonies, archaeological/historical sites, fragile timber). Military suitability maps are based on erosion potential, slope, sensitive areas, transportation factors, and cross-country mobility factors.

The final allocation, Task IX, is actually a two-tiered process. The first tier involves allocating a compartment to a primary and secondary use for natural resource related activities and a primary and secondary use for military activities, irrespective of each other. This is done through a series of exclusionary steps, from the most exclusionary to the least exclusionary. For example, an abundance of archaeological or endangered species sites or a very poor site index may totally exclude mechanized training or certain types of timber production, respectively, from a compartment. In other compartments, there may be an almost total lack of such limiting elements, resulting in no specific activities being excluded. Those areas in which exclusionary factors are clustered may be considered for management as sub-compartments.

The second tier is one of conflict resolution. Resource and military allocations are brought together and compared. In those cases where there are no conflicts, the compartment is allocated to the activity indicated. If, however, there is a conflict, we must look at the secondary allocations to determine compatibility. If a conflict still exists, it is necessary at this point to re-examine the original allocation process for possible adjustments. The ultimate goal is to provide trainers with an area that can both support and enhance their training and will result in the least possible resource damage.

All data for the study were input into either a database management system (DBASE III+) or, where appropriate, digitized into an ERDAS (Earth Resources Data Analysis System) IBM PC-AT based GIS. Digitized military variables included, but were not limited to, slope, erosion potential, vegetative concealment factors, firing ranges and points, transportation factors, streambank slope and gap factors, and landing zones. Resource variables included soil type, forest type, age, and condition class, hydrology, endangered species habitat, archaeological/historical sites, and wildlife habitat. All data were input at a ten meter resolution.

SUMMARY

The methodology will provide both military trainers and natural resource managers with a very useful tool for daily management. As new activities are planned, they can be evaluated for resource compatibility and supportibility before extensive planning is initiated. Through the integration of both training and resource management needs, true multiple use management can be achieved.

Techniques developed in this study are also being applied to Civil Works functions. A limited test on wetlands delineation has been tried with good results. A modification of the technique will also be tried for determining resource capability and developing operational management plans in future work for the Corps of Engineers.

REFERENCES

GENERAL ACCOUNTING OFFICE. "DOD Can Increase Revenues Through Better Use of Natural Resources It Holds in Trust," General Accounting Office, Washington, DC, Procurement, Logistics, and Readiness Division, PLRD-82-9, November, 1981.

JAHN, L.R.; COOK, C.W.; HUGHES, J.D. "An Evaluation of US Army Natural Resource Management Programs on Selected Military Installations and Civil Works Projects," Report to the Secretary of the Army, U.S. Department of the Army, October, 1984.

TERRAIN ANALYSIS CENTER. "Fort Benning, Georgia Terrain Analysis," U.S. Army Engineer Topographic Laboratories, Fort Belvoir, VA, 1976.

ACKNOWLEDGEMENTS

The authors are, respectively, a biologist and a geographer in the Resource Analysis Group, Environmental Resources Division of the Environmental Laboratory (EL), United States Army Engineer Waterways Experiment Station (WES). Mr. H. Roger Hamilton, Chief of the Resource Analysis Group, provided direct supervision for the study. General supervision was provided by Dr. Conrad J. Kirby, Chief of the Environmental Resources Division, and Dr. John Harrison, Chief, Environmental Laboratory. Dr. Robert W. Whalin, P.E., was Technical Director and Col. Dwayne G. Lee was the Commander and Director. The work presented here was funded by the U.S. Army Training and Doctrine command (TRADOC).

THE LAND MANAGERS DILEMMA: MONITORING MULTIDIMENSIONAL RESOURCE ASSOCIATIONS IN A THREE DIMENSIONAL WORLD

James Farley

Arkansas Archeological Survey

INTRODUCTION

The successful management of land resources requires an understanding of the distribution and the interrealtionships which exist between natural and cultural resources, and an appreciation for the manner in which these phenomena change over time and across space. An initial step in the development of such an understanding is the discovery of regularities or patterns in these multidimensional relationships. This process whereby meaningful patterns are identified withinin complex data sets requires a systematic, step-wise approach to analysis.

Because the distribution of archeological resources results from the interaction of a multitude of natural and cultural variables, these data can only be effectively examined within such a framework. Minimal requirements for such an approach include an ability to maintain a diverse variety of data relationships in an accessible format, and the capability to manipulate and quantify these associations to produce interpretable results. Techniques which serve collectively to satisfy these requirements are database management (Martin 1980,1983), geographic information systems analysis (Burroughs 1986), and exploratory data analysis (Tukey 1977, Chambers et al. 1983).

Each of these techniques have been used with success to address analytical problems in archeology (Parker et al. 1985, Kvamme 1985). However, these applications have generally focused on the utility of a single approach such as database management or geographic information systems analysis rather than examining the potential of these mechanisms to compliment one another. This paper examines the results which can be obtained through the integration these techniques. A structured program for analysis is presented in which the individual techniques are used in a complimentary or step wise fashion to increase our understanding of the nature and distribution of archeological resources. Recent results have indicated that such an approach can significantly extend our ability to identfy and interpret the patterns present in the archeological resource base (Limp et al. 1987).

INTRODUCTION TO DBM, GIS, AND EDA

Database management systems (DBM) are designed to facilitate the organization of information preserving data in a format which permits rapid retrieval and presentation. Whether the topology used is hierarchical or relational, database management systems share a body of common attributes:

1) they provide mechanisms for data entry and retrieval
2) they store information in nominal, ordinal and interval scales as well as alphanumeric text based data
3) they are capable of associating diverse information through the use of

keys or pointers
4) they have a limited suite of quantitative capabilities
5) they normally have the capacity to import and export data through a universal format like ASCII

These systems are not well suited to managing multidimensional data in which the logical interlinkages are not known or evident. For instance, databases storing an automotive parts inventory would not initially have an association with data on precipitation cycles. However, a database which reflects a logical understanding of a single problem, or several closely associated problems, can provide insight into potential patterns or anomalies between the data sets. For example, sales of certain auto parts (e.g., windshield wiper blades) could be expected to be related to rainfall periods. Possibly other more subtle and as yet unidentifiable relationship also exist. Thus what is needed is a process through which such subtle relationships may be identified.

One special type of database management system is the geographic information systems (GIS). These systems add a spatial dimension to data and store information commonly associated with traditional maps in layers or themes which can be examined, manipulated, or compared quantitatively using a variety of methods. A simple GIS might contain data layers for archeological sites (point data), networks of transportation and hydrology (vector data), and a topology of regional soils (polygon data), in addition to a base map layer of elevation values. Using this data, the GIS can rapidly identify points or areas which share common sets of attribute values, thus enabling the land manager to profile the composition of the environment. GIS technology relies to a great extent on the visual transmission of information, using sophisticated graphic images to summarize univariate, bivariate, and multivariate distributions across space in the form of a displayed map.

Exploratory data analysis (EDA) is another technique which relies heavily on images to transmit information. However, while a GIS is used to manufacture, manipulate, and model map surfaces, EDA is used to prospect for patterns and anomalies within the data using quantitative techniques and computer graphics. EDA uses the raw data in what Tukey has referred to as numerical detective work (Tukey 1977:1). The function of EDA is to increase our understanding of the distribution of individual variables and the multivariate relationships which may exist between variables. This is accomplished using graphic tools such as boxplots, histograms, crossplots, etc. to insure that the data conforms to the distributional assumptions of more powerful statistical methods (Figure 1). It should be clear that data from a traditional DBMS can be integrated with data from a GIS and the resulting information examined using EDA techniques.

TOOLS FOR MANAGING CULTURAL RESOURCES

Each of the techniques identified above (e.g., DBM, GIS, EDA) is in reality a tool. Like any other type of tool, each has an appropriate range of applications in which they are effective and limitations which make their utilization impractical or inappropriate under certain circumstances. Given this, the immediate problem is to associate particular sets of information or processes needed for effective management and analysis with the correct tool.

Database management systems provide the most basic body of information, supplying the cultural resource manager with a simple inventory of the identified resources under his/her control. The development of a comprehensive database is the most crucial aspect of any program for management. A database which maintains information on site location, cultural affiliation, material assemblage, the range and intensity of environmental and human impacts to the resource, and perhaps the location and intensity of cultural resource surveys provides the foundation for any subsequent analysis. Such a database provides rapid access to the broad spectrum of data relevant to each resource location thereby establishing a basis for comparative analysis between multiple loci within a region. In the absence of a comprehensive database the contribution of more powerful tools such as GIS and EDA is diminished.

A database management system can provide an accurate inventory of existing cultural resources and even some rudimentary environmental data such as elevation, topographic position, physiographic region, and general soil associations (Hilliard and Riggs 1986). However, it does not retain information on nonsite locations and it cannot maintain detailed data in a format which can be effectively used to identify which dimension or combination of dimensions within the natural environment may have contributed to the development of the archeological resource base. Questions such as "did populations with a particular type of economy locate themselves in proximity to specific resources?" or "do people tend to live close to water on arable land?", etc. cannot be adequately addressed using database technology alone.

To investigate questions of this type, extensive environmental information must be preserved in a format which permits data reflecting both site and non-site locations to be modeled. This modeling process must facilitate a multivariate examination of the relationship between the presence or absence of cultural resources and the co-occurrence of one or more dimensions of the natural environment. For instance, how many sites are located on soil type x, or how many sites are located above 300m on north facing slopes within 100m of a permanent water source. Information of this type forms the basis for predictive statements which have the potential to increase our understanding of the mechanisms responsible for site location while simultaneously allowing us to focus our ground level surveys on those areas which are most sensitive.

GIS technology, particularly that which relies on a raster based or grid cell format for data storage is singularly appropriate for problems of this sort. Data which correspond to particular environmental or political dimensions may be easily displayed either separately or as composites overlaying several dimensions of interest simultaneously. For instance, an image which displays the location of all historic farmsteads and their relationship to the modern network of roads may be created. Or conversely, we might examine the distribution of known archaic site locations modeled across elevation in three dimensions with permanent streams superimposed on the image. This type of capability provides the archeologist with the opportunity to rapidly explore a number of relationships which might otherwise go unnoticed. In addition, a raster based GIS is uniquely suited to applications directed towards quantitative analysis and the development predictive statements (Kvamme 1985, 1986; Kvamme and Jochim 1985). Using the GIS, a number of reports, coincidence tabulations, simple statistics, and proximity types of analysis can be conducted, thereby creating a foundation which can be used in more stringent quantitative applications.

Databases and geographic information systems provide qualitative information defining the character and spatial distribution of resources. They also provide a limited amount of quantitative data. They do not provide facilities to rigorously investigate the underlying distribution of the raw data, nor do they permit us to examine these distributions to insure that they conform to the basic assumptions of sophisticated statistical applications. To meet these requirements the capabilities of EDA must be employed. For instance, the results of our previous anlysis using DBM and GIS might suggest that 75% of all historic farmsteads are located in flat areas close to primary drainages. This is a legitemate observation derived from an examination of observable phenomena. However to investigate the nature of this distribution as a prelude to composing predictive statements concerning the observed distribution more objective measurements must be made.

Using EDA techniques such as histograms, cross plots and symbolic plots of quantiles we can ascertain wether the distribution differs significantly from that which might be expected (Figures 1 and 2). In addition, these methods allow us to evaluate the homogeneity of our samples and provide us with the capacity to identify aberrant observations or outliers. Using this information we can more effectively stratify the population and direct our efforts to developing explanations for the presence of annomolies. Returning to the example above, we might determine that historic farmsteads actually represent a bimodal distribution with a large number of sites located on flat surfaces in association with major streams and a smaller number of sites restricted to upland locations. These differences might reflect cultural practices, kinship ties, functional differences between the sites or economic factors. Using this information the data can be subset creating two homogeneous samples which can then be re-examined with greater accuracy. This pattern of examiniation, subsetting and re-examiniation in which increasingly fine approximations of data set structure and composition are realized is the essence of EDA and an essential element in any program attempting to comprehend and explain multidimensional phenomena.

The results of these types of analysis can be used to construct preliminary models of site location. Models of this type have been referred to as overview or initial management level and can be used to make preliminary predictive statements concerning the nature and the distribution of resources as an aid to the planning process. Additionally, these constructs provide a foundation for the development of robust compliance level models which are derived from more sophisticated quantitative techniques (Limp 1987).

INTEGRATING TOOLS FOR ANALYSIS

To illustrate the effective manner in which these techniques can be integrated to improve cultural resource management capabilities, the results from a recently completed project in north central Arkansas are presented. This project involved the step-wise development of initial management level predictive models for site occurrence within the boundaries of a hypothetical installation referred to as Camp Foothills. The Camp Foothills installation

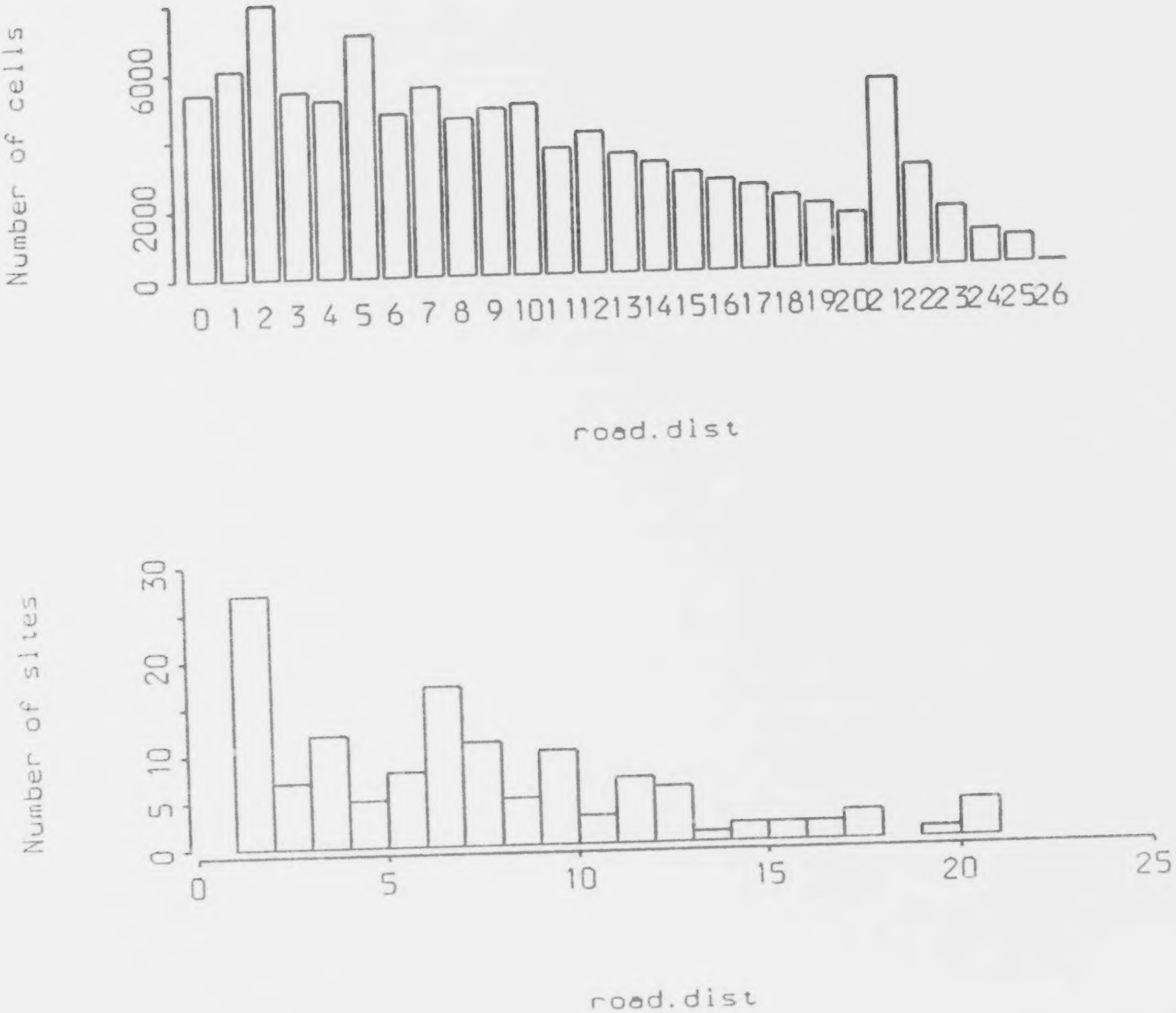


FIGURE 1. COMPARATIVE DISTRIBUTIONS OF DISTANCE TO ROAD FOR ALL CELLS AND FOR CELLS WITH SITES IN CAMP FOOTHILLS

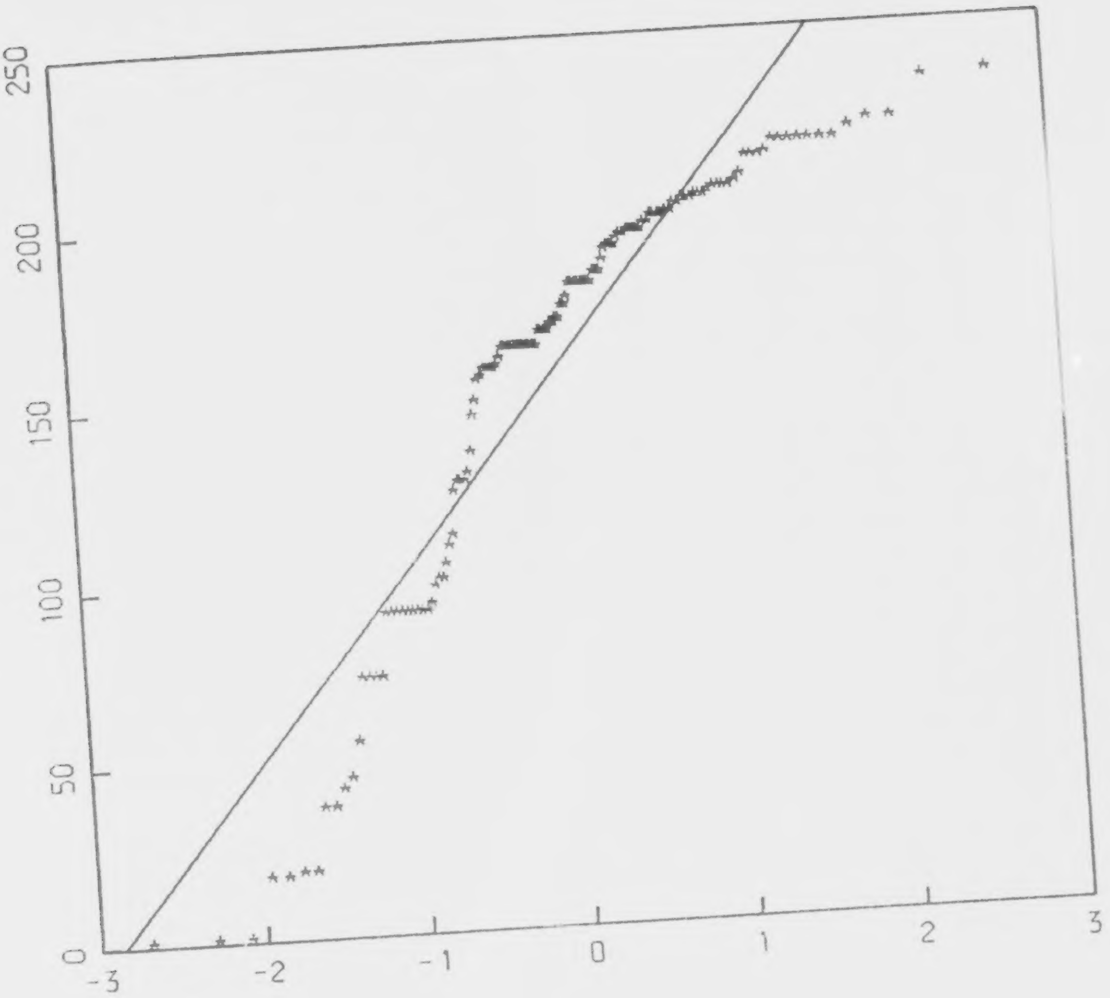


FIGURE 2. QUANTILE PLOT OF ELEVATION AGAINST NORMAL DISTRIBUTION

encompasses approximately 270 square kilometers and is located in the rugged uplands of the Ozark Mountains.

A preliminary cultural resources profile of the Camp Foothills installation was developed using the AMASDA database system (Hilliard and Riggs 1986). AMASDA is a comprehensive statewide database which contains information on more than 20,000 cultural resources. A variety of observations (135 categories) are recorded for each resource in the database. The profile of Camp Foothills indicated that there were 149 archeological sites representing 187 discrete cultural components (Table 1). These figures yield a site density of .55 per square kilometer which is substantially higher than either the .17 figure calculated for the surrounding region or the .13 value for the entire state. The higher site density figure for the Camp Foothills installation can be attributed to the high volume of archeological work conducted in the area.

The data in AMASDA also enabled us to ascertain and compare the distribution of resources by cultural affiliation, site type, elevation, and distance to water for both Camp Foothills and the surrounding region (Springfield Plateau/Boston Mountains) while computing the relative integrity of the known resources using an index of site destruction and observations on the primary factors affecting site stability between these areas (Tables 1-3). The extremely high percentage of Camp Foothills sites located within 100m of water (67%) and the preponderance of large lithic scatters and bluffshelter sites is of particular note. This information might serve as a basis for developing strategies of differential survey intensity based on environmental attributes or as a preliminary step toward formulating a management plan which provides for the selective preservation of specific types of archeological sites.

Using the data obtained from the AMASDA system as a foundation for an analysis of the structure of the archeological resources located within Camp Foothills, a simple GIS was constructed. This was a feasibility study designed to demonstrate the utility of this approach using only a minimal number of data layers. The map themes developed for this GIS consisted of point plot data for archeological site location obtained from AMASDA; 1:250,000 DMA DEM data; DLG vector based data for roads, streams, and archeological survey transects and polygon data reflecting property ownership. Additionally, a number of derived map layers were developed for slope, aspect, distance to water and distance to the nearest road.

These data layers were input into the GRASS GIS developed at the U.S. Army Corps of Engineers Construction Engineering Research Laboratories (Goran et al. 1987). The DMA DEM data was reclassified to emphasize the primary features which dominate the environment at Camp Foothills. Lower elevations located in the northeastern and northwestern sectors of the installation are exclusively associated with the presence of major streams and account for approximately 10.7% of the total area. Using the DEM data, a map theme reflecting slope was developed. The coincidence tabulation report from the GRASS GIS indicated that 56.9% of the area exhibited a slope greater than or equal to 7 degrees (Table 4). On the other end of the spectrum, only 21.9% of the area can be classified as flat or relatively flat with a slope of 3 degrees or less.

TABLE 1. CULTURAL AFFILIATION

Cultural Affiliation	Camp Foothills		Springfield Plateau Boston Mtns.	
	Count	Percent	Count	Percent
(AT) Dev. Settl.	3	2	78	2
(AT) Dev. Settl., City/Town	4	2	39	1
(AT) Dev. Settl., Rural, Agric.	3	2	584	14
(AT) Late Holo, Sedentary			1	
(AT) Late Holo, Semi-Sedentary			32	1
(AT) Pioneer Settlement			22	1
(AT) Pioneer Settlmnt, Agric.	21	11	246	6
(NA) Cherokee			1	
(NA) Osage			1	
Afro-American			2	
Anglo-American	4	2	123	3
Archaic Period	25	13	521	12
Archaic, Early	4	2	49	1
Archaic, Early/Middle			2	
Archaic, Late	1	1	109	3
Archaic, Middle			44	1
Archaic, Middle/Late			2	
Archaic, Terminal			1	
Baytown Period			1	
Baytown, Late			1	
Caddo (Prehistoric)			28	1
Caddo, Late			1	
Caddo, Middle			1	
Civil War			9	
Coles Creek (Period/Culture)			1	
Contact Period			4	
Contact, Post 1800 AD			1	
Dalton (Period/Culture)	1	1	42	1
European			17	
Fourche Maline			4	
Fourche Maline, Early			1	
Historic Period	6	3	77	2
Historic, Other			1	
Huntsville Phase			1	
Loftin Phase			1	
Mississippi Period			38	1
Mississippi, Early			1	
Mississippian	11	6	253	6
Mississippian, Early			2	
Mississippian, Late			3	
Mississippian, Middle			1	
Native American-Historic	1	1	34	1
Neosho Focus			2	
Paleo-Indian Period			14	
Prehistoric	78	42	1533	36
Protohistoric			2	
Unknown Cultural Affiliation	5	3	46	1
War Eagle Phase			2	
Woodland Period	19	10	263	6
Woodland, Early	1	1	38	1
Woodland, Late			26	1
Woodland, Middle			5	
	187		4311	

TABLE 2. (A) SITE TYPE AND (B) ELEVATION

(A) (A)	Camp Foothills Count	Camp Foothills Percent	Springfield Plateau Boston Mtns. Count	Springfield Plateau Boston Mtns. Percent
Unknown scatter			223	4
Single artifact	2	1	88	2
Scatter < 100 sq m	8	4	184	4
Scatter > 100 sq m	46	23	1535	31
Scatter + Midden			89	2
Mound	1	0.5	19	0.5
Bluffshelter/cave	75	37	718	14
Rock Art	1	0.5	20	0.5
Quarry			3	
Items only in test			48	1
Items in eroded area			174	3
Archival site	29	14	861	17
GLO site	21	10	256	5
Structure present	19	9	771	15
Total	202		4989	

(B) Elevation	Camp Foothills Count	Camp Foothills Percent	Springfield Plateau Boston Mtns. Count	Springfield Plateau Boston Mtns. Percent
< 800	10	7	969	28
801 - 900	5	4	186	6
901 - 1000	10	7	268	8
1001 - 1100	2	1	334	10
1101 - 1200	7	5	545	16
1201 - 1300	7	5	329	10
1301 - 1400	6	4	198	6
1401 - 1500	15	10	144	4
1501 - 1600	6	4	198	6
1601 - 1700	6	4	56	2
1701 - 1800	18	12	90	3
1801 - 1900	28	19	87	3
1901 - 2000	20	13	66	2
2001 - 2100	9	6	23	1
> 2100	--	--	21	1
	149		3409	

TABLE 3. (A) DISTANCE TO WATER, (B) DEGREE OF DESTRUCTION AND (C) DESTRUCTION TYPES
(C) DESTRUCTION TYPES

(A) Distance to Water	Camp Foothills		Springfield Plateau Boston Mtns.	
	Count	Percent	Count	Percent
0 m	55	37	874	25
51 - 50 m	44	30	1044	30
51 - 100 m	13	9	554	16
101 - 250 m	14	9	565	16
251 - 500 m	17	11	331	10
501 - 1000 m	6	4	81	2
> 1000 m	0	0	10	0.3
	149		3459	

(B) Degree of Destruction	Camp Foothills		Springfield Plateau Boston Mtns.	
	Count	Percent	Count	Percent
Undisturbed	5	3.4	113	3.4
Minor	3	2.0	137	4.1
Moderate	10	6.7	130	3.9
Major	12	8.1	191	5.7
Total	0		22	0.7
Unknown	119	79.9	2756	82.3
	149		3349	

(C) Destruction Type	Camp Foothills		Springfield Plateau Boston Mtns.	
	Count	Percent	Count	Percent
Natural causes	28	30.8	1240	33.7
Construction general	0		193	5.2
Road construction	28	30.8	366	9.9
Drainage construction	0		26	0.7
Agriculture	7	7.7	873	23.7
Timbering	0		49	1.3
Land leveling	0		82	2.2
Periodic inundation	5	5.5	192	5.2
Indefinite inundation	1	1.1	133	3.6
Buried	0		19	0.5
Potting/looting	18	19.8	318	8.6
Extensive collecting	4	4.4	193	5.2
	91		3684	

The archeological resources were stratified along temporal dimensions and examined in association with a number of environmental attributes. The distribution of all prehistoric sites suggests that sites will be located on flat surfaces between 503-628m amsl and that they will be within 100m of a permanent stream (Table 4). Historic period occupations, however, show a bimodal distribution in relation to elevation and do not appear to be as dependent on proximity to a permanent stream (Table 5). By further sub-setting these historic data into Pioneer occupations and Developed Settlement occupations (periods which reflect both temporal and cultural differences), we see that the bimodality in settlement location reflects fundamental differences between these two groups.

These earlier Pioneer period occupations are located at lower elevations in association with major streams (Table 6); a settlement pattern which reflects that of prehistoric populations. The later Developed Settlement period occupations closely approximate the distribution of modern populations and are found at locations both in close proximity to streams as well as in much wider, less constrained areas. The difference reflects the changing economic infrastructure of the area. The earlier settlers in the area, like the prehistoric inhabitants, choose the fertile floodplains with nearby surface water. Latter inhabitants, however, had to adapt to the governmentally applied General Land Office land grid as well as to transportation routes which followed the path of least resistance across the ridge tops. The former dependence on permanent streams was relaxed as water was obtained through dug wells and roof filled cisterns.

Following the GIS based examination, the historic period site data within the GIS was downloaded from GRASS and loaded into the "S" system for data analysis and graphics (Becker and Chambers 1984). ("S" is a software package developed at Bell Laboratories specifically to perform EDA.) Using the pattern searching techniques common to exploratory data analysis, the preliminary trends identified using AMASDA and GRASS were more intensively examined. Histograms of archeological site location (for the entire sample of historic sites, and for the subsets of Pioneer Settlement and Developed Settlement) measured against elevation, distance to roads and streams clearly reflect the bivariate patterns suggested by the GIS (Figures 3, 4, and 5).

These patterns are again confirmed through correlation analysis and quantile plots against the normal distribution (Figure 6). Phenograms generated using clustering algorithms, "stars" and "faces," provided excellent discrimination in the multivariate relationships between distance to roads, distance to nearest stream, elevation and slope for historic period occupations (Figures 7, 8, and 9). The latter methods are unique to EDA and illustrate its basic premise.

The techniques, "stars" and "faces", were used to depict the multidimensional range of variation within the population of historic sites. These methods construct a graphic images to illustrate the proportional measurement for each variable at each location. In the "faces" image each feature corresponds to a particular dimension within the data. The area of the "face" measures slope, the shape of the "face" measures aspect, the length of the nose indicates relative distance to roads, etc. For the "stars," the length of each ray is proportional to the value of the specific variable.

TABLE 4. COMPARISON OF THE DISTRIBUTION OF ALL REPORTED PREHISTORIC CULTURAL RESOURCES AND (A) SLOPE, (B) SLOPE RECLASSIFIED AND (C) ELEVATION

(A) Slope (classified)

Category	All Cells in Area N	 %	Cells under DOD ownership N	 %
No data	1276	1.3	(15403)	--
0 degree	9770	9.7	7324	8.6
1 - 3 degrees	12322	12.2	9738	[illegible]
4 - 6 degrees	20036	19.9	17153	20.1
7 - 12 degrees	31146	30.9	27567	[illegible]
13 - 20 degrees	19378	19.2	17341	20.3
21 degress and greater	6872	6.8	6269	7.3
Totals	100800		85392	

(B) Layer: slope.reclass Slope reclassified

cells in analysis window: 100800
sites in analysis window: 134

Site Characteristics	cells cover	% cover	expected sites	actual sites	chi square	degrees of freedom
(0) no data	1276			0		
(1) 0 degrees	9770	9.8	13.2	17	1.124	1
(2) 1 degree	12322	12.4	16.6	30	10.839	1
(3) 4 degrees	20036	20.1	27.0	34	1.029	1
(4) 7 degrees	31146	31.3	41.7	24	7.671	1
(5) 13 degrees	19378	19.5	26.1	26	0.000	1
(6) 21 degrees	6872	6.9	9.3	3	4.229	1
Totals	99524	100.0	134.0	134	25.653	5

(C) Layer: elev.classes elevation in meters (rescaled)

cells in analysis window: 100800
sites in analysis window: 134

Site Characteristics	cells cover	% cover	expected sites	actual sites	chi square	degrees of freedom
(0) no data	157			2		
(1) 250 thru 292	1507	1.5	2.0	5	4.625	1
(2) 293 thru 334	3756	3.7	4.9	4	0.174	1
(3) 335 thru 376	5573	5.5	7.3	5	0.730	1
(4) 377 thru 418	6503	6.5	8.5	13	2.344	1
(5) 419 thru 460	11867	11.8	15.6	8	3.676	1
(6) 461 thru 502	16036	[illegible]	[illegible]	4	13.793	1
(7) 503 thru 544	19125	19.0	25.1	28	0.337	1
(8) 545 thru 586	21847	21.7	28.7	40	4.493	1
(9) 587 thru 628	10683	10.6	14.0	23	5.766	1
(10) 629 thru 670	3746	3.7	4.9	2	1.727	1
Totals	100643	100.0	132.0	132	37.667	9

TABLE 5. COMPARISON OF THE DISTRIBUTION OF ALL REPORTED HISTORIC CULTURAL RESOURCES AND (A) DISTANCE TO SECOND ORDER OR GREATER STREAMS AND (B) ELEVATION

(A)

```
==========================================================================
Layer: st45.dist              Proximity analysis

cells in analysis window:       100800
sites in analysis window:          134
                                                                         degrees
                                   cells      %    expected  actual   chi      of
Site Characteristics               cover    cover    sites    sites  square  freedom
--------------------              -------  ------- -------  ------  -------  -------
(  0) Locations from which dis      778                         0
(  1) 0.00 to 50.00 meters         1456      1.5      2.0       9   25.476      1
(  2) 50.00 to 100.00 meters       2030      2.0      2.7      10   19.450      1
(  3) 100.00 to 250.00 meters      4789      4.8      6.4       7    0.053      1
(  4) 250.00 to 500.00 meters      7253      7.3      9.7       0    9.717      1
(  5) 500.00 to 750.00 meters      6807      6.8      9.1       0    9.119      1
(  6) 750.00 to 1000.00 meters     6719      6.7      9.0       4    2.779      1
(  7) 1000.00 to 1500.00 meter    12649     12.6     16.9      28    7.211      1
(  8) 1500.00 to 2000.00 meter    11392     11.4     15.3      15    0.004      1
(  9) 2000.00 to 3000.00 meter    18438     18.4     24.7      15    3.810      1
( 10) 3000.00 to 4000.00 meter    16594     16.6     22.2      24    0.141      1
( 11) 4000.00 to 5000.00 meter     9613      9.6     12.9      17    1.319      1
( 12) Greater than 5000.00 met     2282      2.3      3.1       5    1.235      1
                                  -------  ------- -------  ------  -------  -------
        Totals                   100022    100.0    134.0     134   80.354     11
==========================================================================
```

(B)

```
==========================================================================
Layer: elev.classes           elevation in meters (rescaled)

cells in analysis window:       100800
sites in analysis window:           35
                                                                         degrees
                                   cells      %    expected  actual   chi      of
Site Characteristics               cover    cover    sites    sites  square  freedom
--------------------              -------  ------- -------  ------  -------  -------
(  0) no data                       157                         1
(  1) 250 thru 292                 1507      1.5      0.5       0    0.509      1
(  2) 293 thru 334                 3756      3.7      1.3       6   17.640      1
(  3) 335 thru 376                 5573      5.5      1.9       3    0.663      1
(  4) 377 thru 418                 6503      6.5      2.2       3    0.294      1
(  5) 419 thru 460                11867     11.8      4.0       4    0.003      1
(  6) 461 thru 502                16036     15.9      5.4       2    2.155      1
(  7) 503 thru 544                19125     19.0      6.5       4    0.937      1
(  8) 545 thru 586                21847     21.7      7.4       2    3.922      1
(  9) 587 thru 628                10683     10.6      3.6      10   11.317      1
( 10) 629 thru 670                 3746      3.7      1.3       0    1.265      1
                                  -------  ------- -------  ------  -------  -------
        Totals                   100643    100.0     34.0      34   38.705      9
==========================================================================
```

TABLE 6. COMPARISON OF THE DISTRIBUTION OF ALL REPORTED PIONEER SETTLEMENT ADAPTATION TYPE AND (A) DISTANCE TO FOURTH ORDER STREAM, (B) SLOPE AND (C) DISTANCE TO SECOND ORDER OR GREATER STREAMS

(A)

```
Layer: st45.dist              Proximity analysis

cells in analysis window:      100800
sites in analysis window:          35
                                                                          degrees
                                  cells      %     expected actual   chi      of
Site Characteristics              cover    cover    sites    sites  square  freedom
--------------------             ------- ------- --------- ------ -------- -------
  0) Locations from which dis      778                        0

  1) 0.00 to 50.00 meters         1456      1.5       0.5      3   12.174      1
  2) 50.00 to 100.00 meters       2030      2.0       0.7      4   15.235      1
  3) 100.00 to 250.00 meters      4789      4.8       1.7      5    6.294      1
  4) 250.00 to 500.00 meters      7253      7.3       2.5      1    0.932      1
  5) 500.00 to 750.00 meters      6807      6.8       2.4      1    0.802      1
  6) 750.00 to 1000.00 meters     6719      6.7       2.4      0    2.351      1
  7) 1000.00 to 1500.00 meter    12649     12.6       4.4      2    1.320      1
  8) 1500.00 to 2000.00 meter    11392     11.4       4.0      1    2.237      1
  9) 2000.00 to 3000.00 meter    18439     18.4       6.5      3    1.847      1
 10) 3000.00 to 4000.00 meter    16394     16.6       5.8      8    0.829      1
 11) 4000.00 to 5000.00 meter     9613      9.6       3.4      5    0.795      1
 12) Greater than 5000.00 met     2282      2.3       0.8      2    1.603      1
                                ------- ------- --------- ------ -------- -------
     Totals                     100022    100.0      35.0     35   46.924     11
***********************************************************************************
```

(B)

```
***********************************************************************************

Layer: slope.reclass          Slope reclassified

cells in analysis window:      100800
sites in analysis window:          17
                                                                          degrees
                                  cells      %     expected actual   chi      of
Site Characteristics              cover    cover    sites    sites  square  freedom
--------------------             ------- ------- --------- ------ -------- -------
(  0) no data                     1276                        0

(  1) 0 degrees                   9770      9.8       1.7      4    3.255      1
(  2) 1 degree                   12322     12.4       2.1      6    7.209      1
(  3) 4 degrees                  20035     20.1       3.4      3    0.052      1
(  4) 7 degrees                  31146     31.3       5.3      2    2.072      1
(  5) 13 degrees                 19378     19.5       3.3      2    0.518      1
(  6) 21 degrees                  6872      6.9       1.2      0    1.174      1
                                ------- ------- --------- ------ -------- -------
     Totals                      99524    100.0      17.0     17   14.282      5
***********************************************************************************
```

(C)

```
***********************************************************************************

Layer: st45.dist              Proximity analysis

cells in analysis window:      100800
sites in analysis window:          17
                                                                          degrees
                                  cells      %     expected actual   chi      of
Site Characteristics              cover    cover    sites    sites  square  freedom
--------------------             ------- ------- --------- ------ -------- -------
(  0) Locations from which dis     778                        0

(  1) 0.00 to 50.00 meters        1456      1.5       0.2      2   12.411      1
(  2) 50.00 to 100.00 meters      2030      2.0       0.3      3   20.420      1
(  3) 100.00 to 250.00 meters     4789      4.8       0.8      3    5.871      1
(  4) 250.00 to 500.00 meters     7253      7.3       1.2      1    0.044      1
(  5) 500.00 to 750.00 meters     6807      6.8       1.2      0    1.157      1
(  6) 750.00 to 1000.00 meters    6719      6.7       1.1      0    1.142      1
(  7) 1000.00 to 1500.00 meter   12649     12.6       2.1      0    2.150      1
(  8) 1500.00 to 2000.00 meter   11392     11.4       1.9      0    1.926      1
(  9) 2000.00 to 3000.00 meter   18439     18.4       3.1      2    0.410      1
( 10) 3000.00 to 4000.00 meter   16394     16.6       2.8      1    1.175      1
( 11) 4000.00 to 5000.00 meter    9613      9.6       1.6      3    1.142      1
( 12) Greater than 5000.00 met    2282      2.3       0.4      2    6.701      1
                                ------- ------- --------- ------ -------- -------
     Totals                     100022    100.0      17.0     17   54.570     11
***********************************************************************************
```

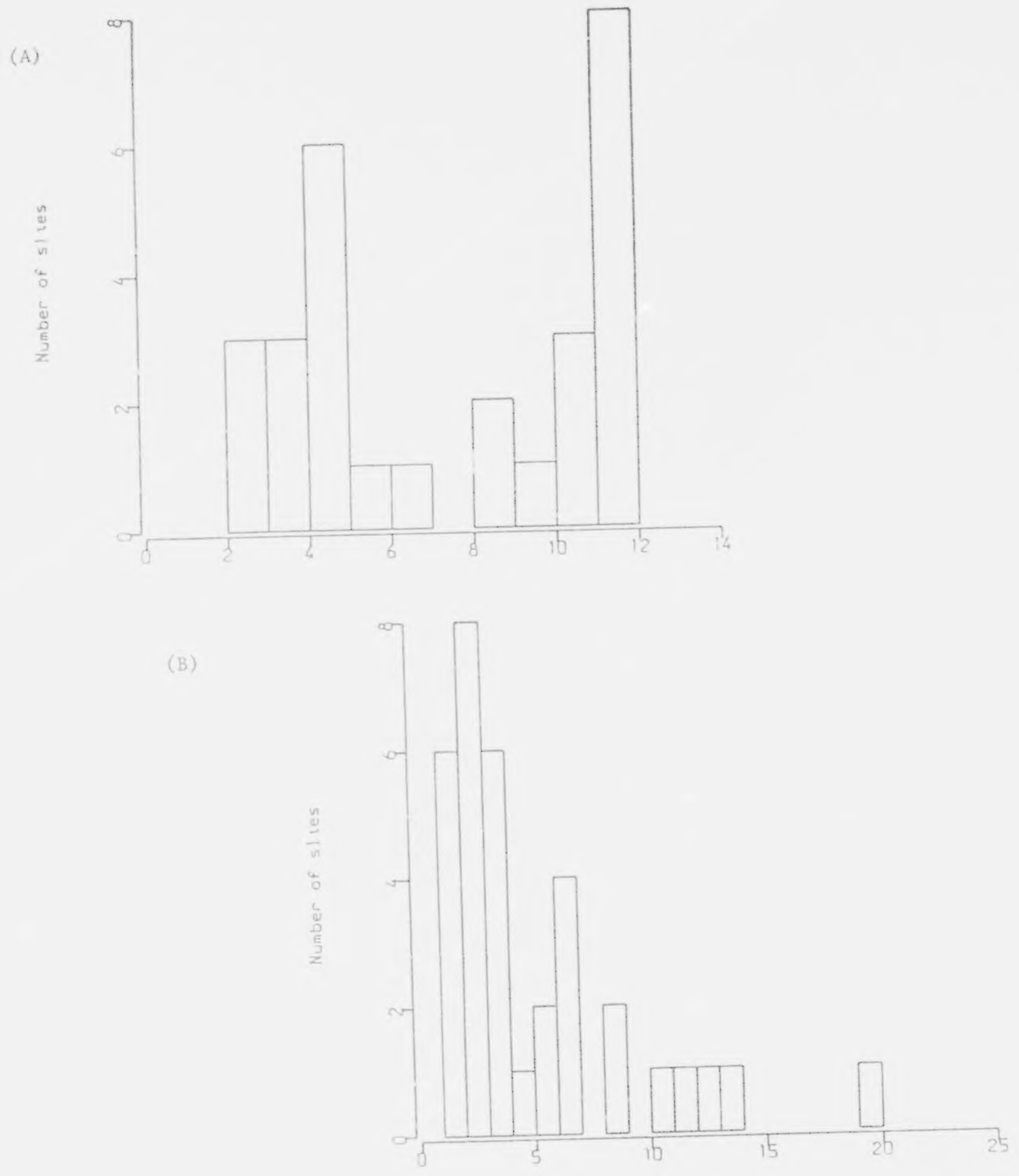


FIGURE 3. HISTORIC SITE DISTRIBUTION IN RELATION TO MAJOR DRAINAGES (A) and road network (B)

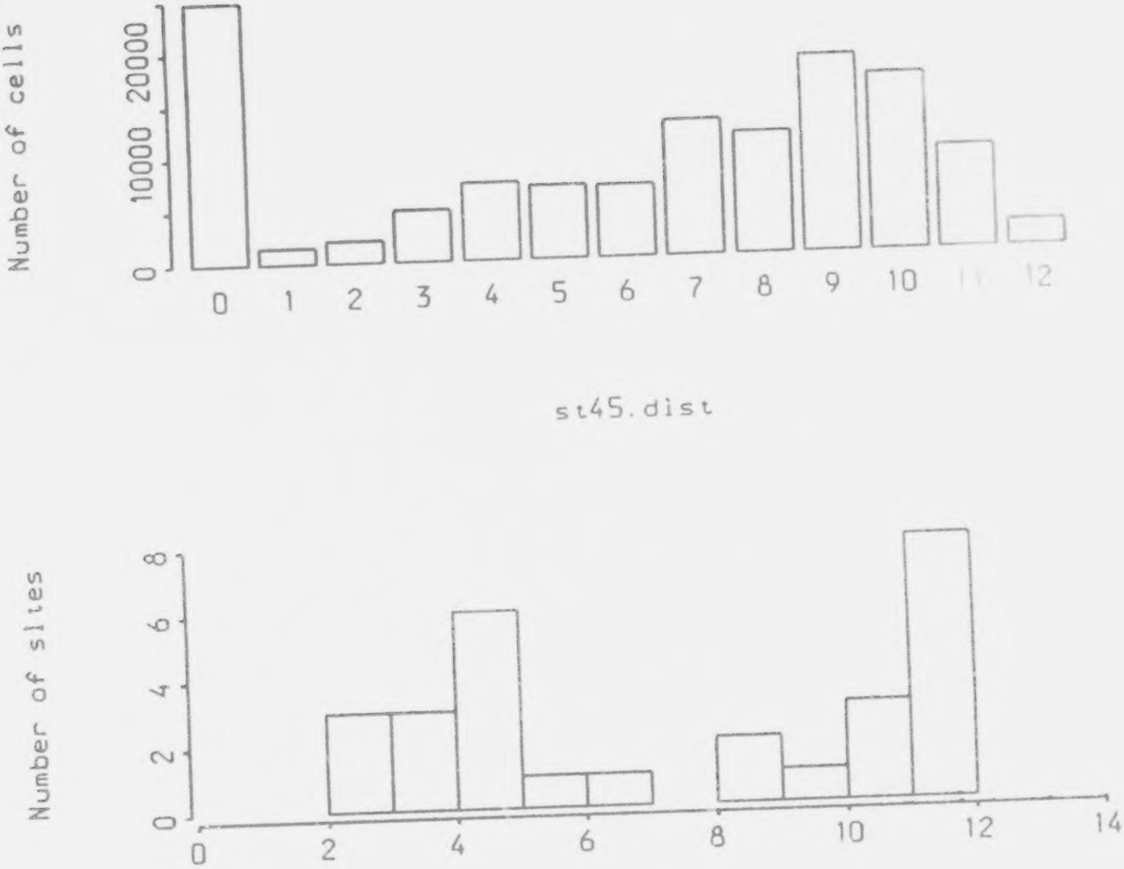


FIGURE 4. RELATIVE DISTANCE TO MAJOR DRAINAGES FOR SITE AND NON-SITE LOCATIONS IN CAMP FOOTHILLS

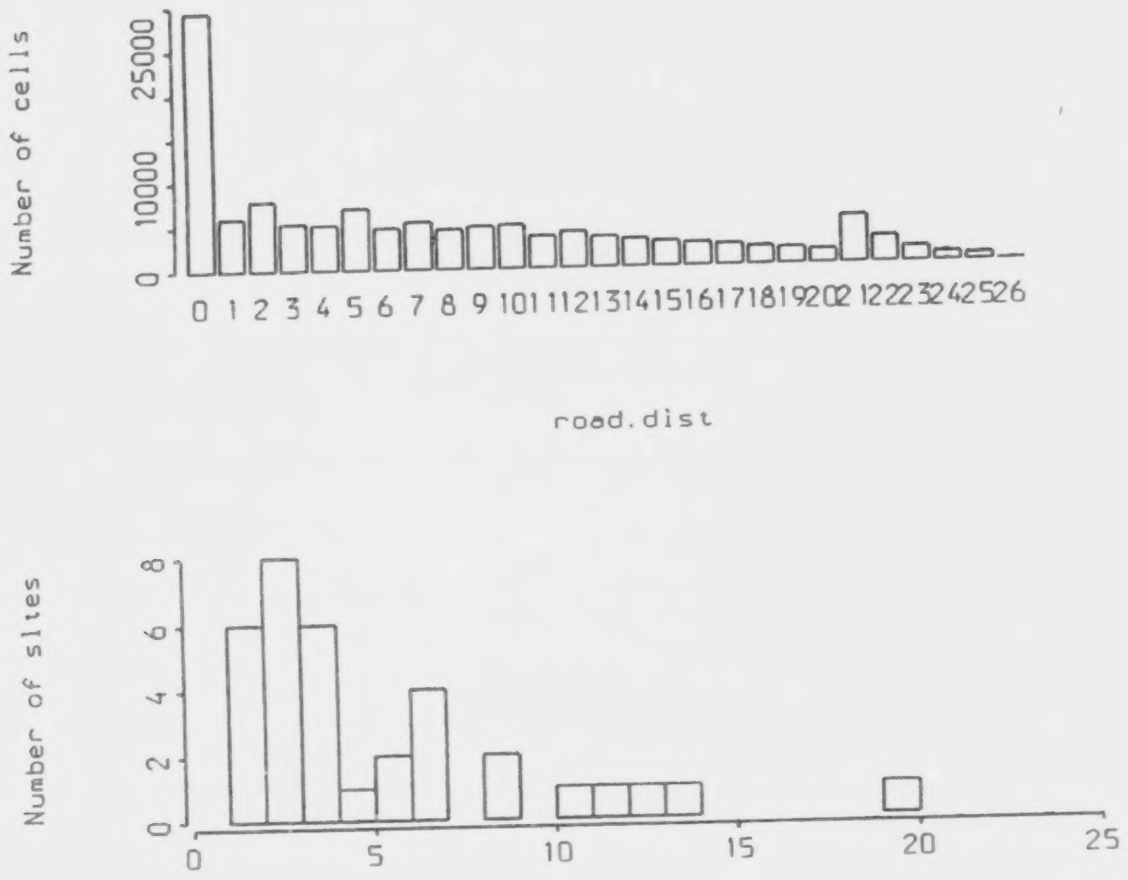


FIGURE 5. RELATIVE DISTANCE FROM ROAD FOR SITE AND NON-SITE LOCATIONS WITHIN CAMP FOOTHILLS

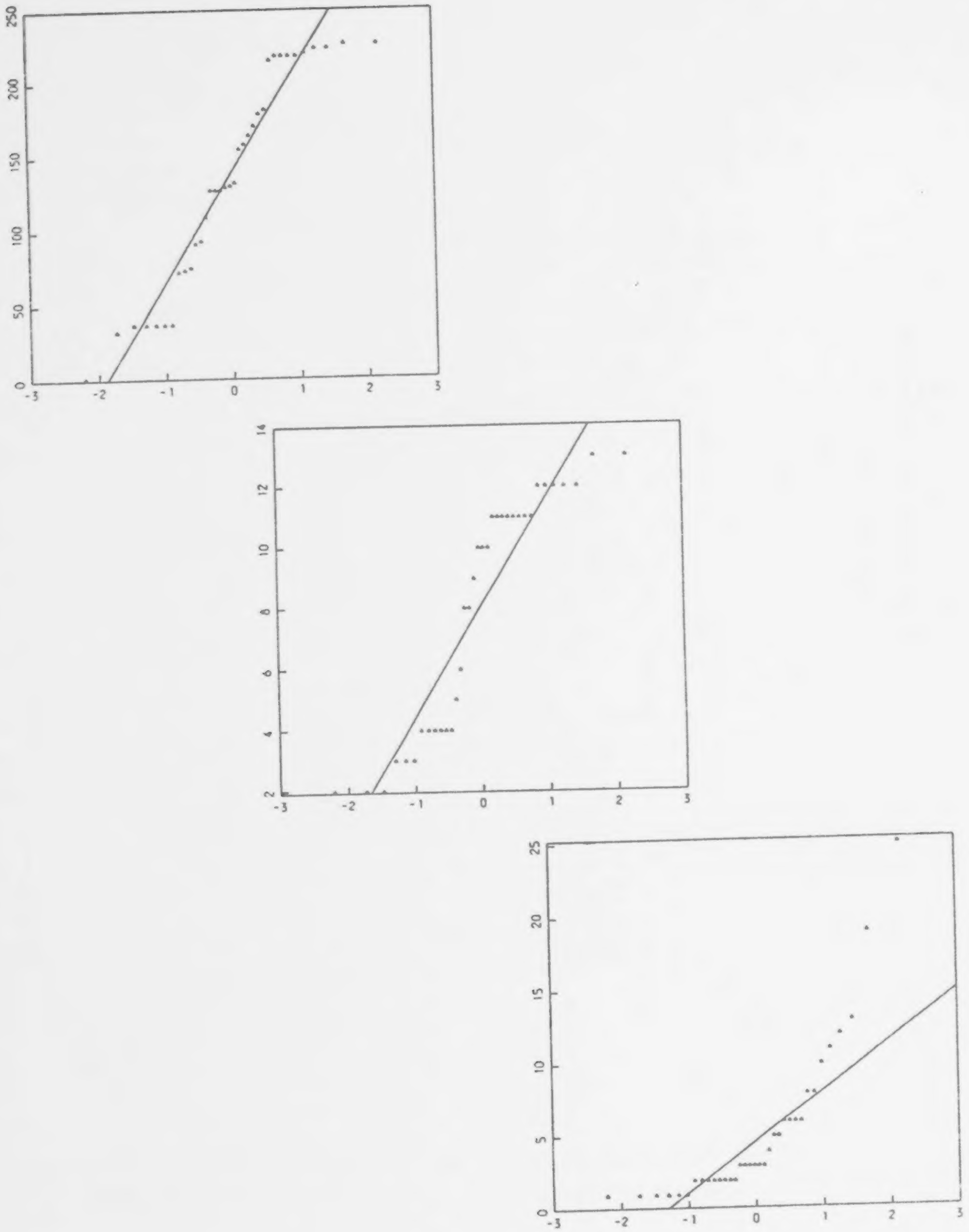


FIGURE 6. QUANTILE PLOTS SHOWING THE DISTRIBUTION OF (A) ELEVATION, (B) DISTANCE TO MAJOR DRAINAGE AND (C) DISTANCE TO ROAD

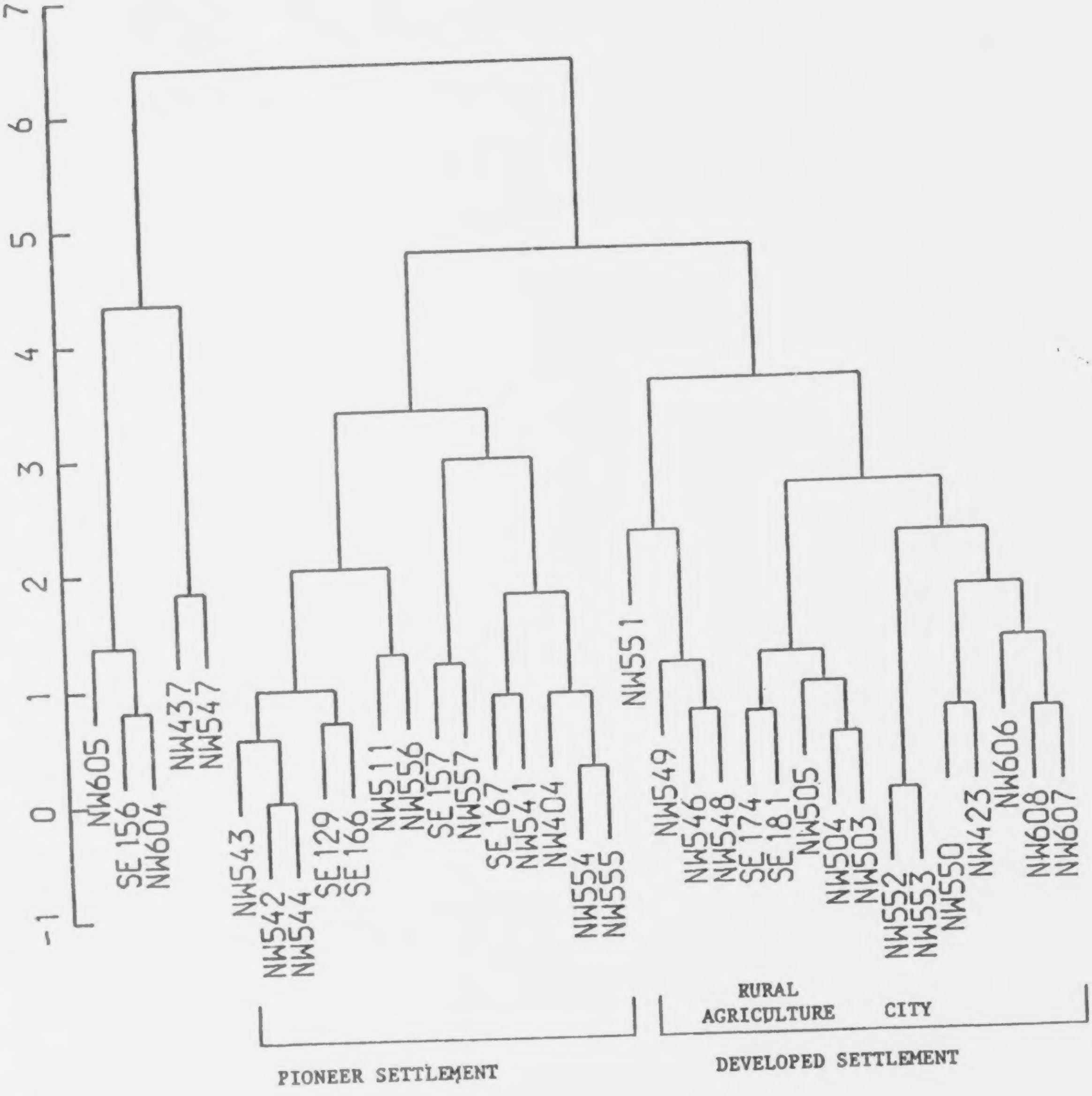

-1
0
1
2
3
4
5
6
7
NW605
SE 156
NW604
NW437
NW547
NW543
NW542
NW544
SE 129
SE 166
NW511
NW556
SE 157
NW557
SE 167
NW541
NW404
NW554
NW555
NW551
NW549
NW546
NW548
SE 174
SE 181
NW505
NW504
NW503
NW552
NW553
NW550
NW423
NW606
NW608
NW607
RURAL AGRICULTURE
CITY
PIONEER SETTLEMENT
DEVELOPED SETTLEMENT

FIGURE 7. PHENOGRAM OF HISTORIC PERIOD OCCUPATION

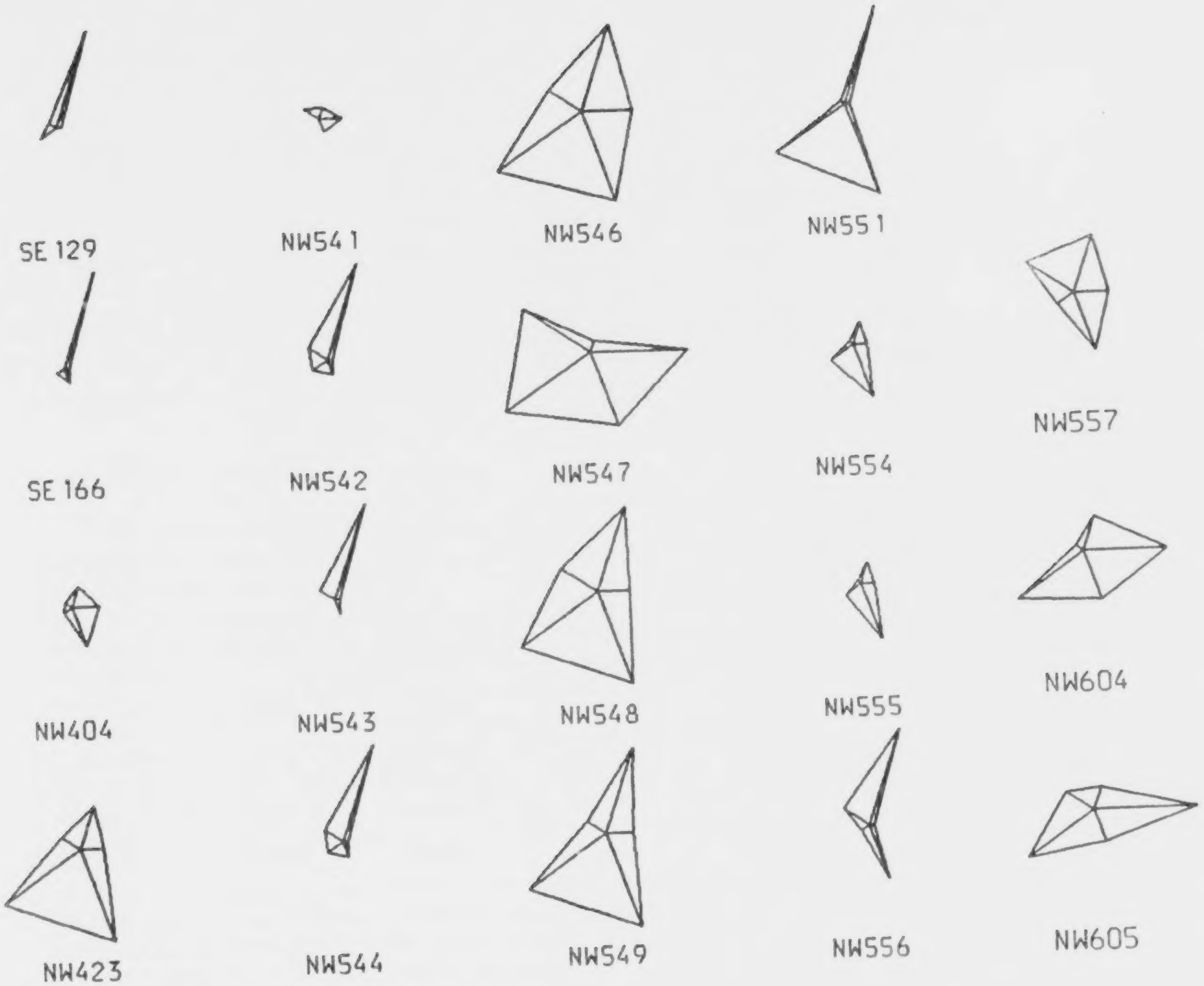


FIGURE 8. STARS SHOWING MULTIDIMENSIONAL RANGE OF VARIATION IN SELECTED HISTORIC PERIOD OCCUPATIONS

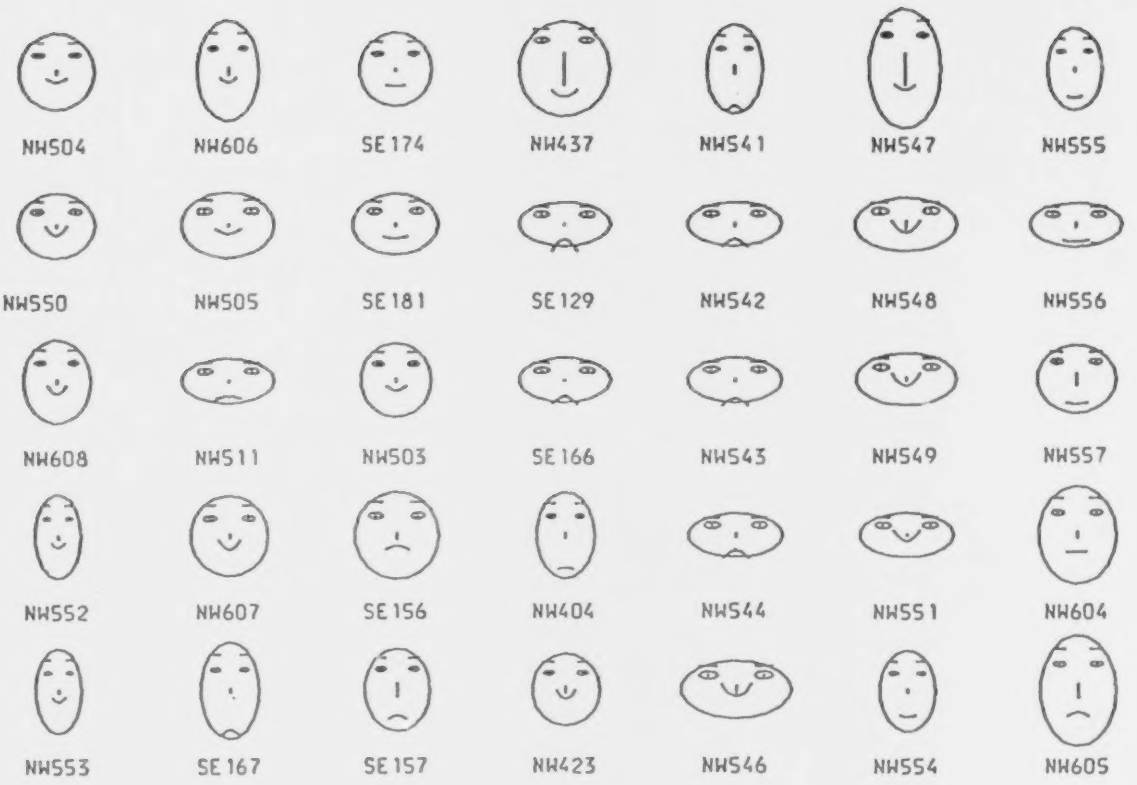


FIGURE 9. FACES SHOWING MULTIDIMENSIONAL RANGE OF VARIATION IN HISTORIC PERIOD OCCUPATION (SITES NW504-NW503, FIRST THREE COLUMNS = DEVELOPED SETTLEMENT. THE REMAINDER ARE PIONEER SETTLEMENT PERIOD.)

While the "faces" at first appear humerous, their use reflects a serious concern with the way in which humans recognize and process information. Most quantitative work is symbolic in nature with results indicated by letters and numbers (e.g., $r^2 = 0.85$). Humans have a strong and largely untapped capability to recognize visual patternings. The use of the "face" is based on the fact that humans have developed particularly subtle attributes in facial recognition (Chernoff 1973,1978). Applications of this type serve to enhance efforts at pattern discovery.

The results of these analysis, which admittedly are based on a limited suite of environmental variables, permitted us to construct deductive models of site location for prehistoric village sites, prehistoric bluffshelters, and historic site locations. Using the basic "expert system" interface in GRASS, maps were prepared which displayed the spatial distributions of the various complex weighings of environmental properties associated with these models. These maps provided the comparative base for evaluating the potential impact assiociated with alternative training area locations.

CONCLUSION

An integrated approach of this type is beneficial to short term management, long range planning efforts and to the scientific investigation of archeological resources. The short term management environment is essentially devoted to problem solving. The manager simply desires to achieve a particular goal while remaining in compliance. In these instances a project needs to be completed or a training area needs to be identified and put into use and the manager simply wants to resolve the issue in a timely fashion. The implimentation of a structured program for data collection and anlysis such as that presented above will provide the manager with the information needed to make the informed decisions needed to accomplish this. In addition, the models become more robust over time with the accumulation of additional data thereby insuring that the process will increase in efficiency with use.

The information obtained from initial models and subsequent interations of the modelling process creates an atmosphere in which a structured program for resource management can evolve. Using the initial model as a foundation a long term planning strategy can be developed as a guide to selecting reconnaisance areas; to identifying sites within the total archeological resource base which require further investigation or special conservation measures; and to schedule the level and intensity of cultural resource management activities within the boundaries of human and fiscal limitations. Because these techniques (DBM, GIS, EDA), require the systematic collection and analysis of data to develop a standardized body of information a comparative basis for resource evaluation is created. This in turn creates the possibility of developing a rational criteria for implementing preservation measures.

Finally, the application of these techniques to problems of cultural resource management helps to maximize the "scientific potential" of the resource base. Because these tools extend our understanding of the distribution of the resources and our appreciation for the mechanisms responsible for that distribution our ability to conduct problem oriented research is enhanced. This is exmplified by the results presented above which indicate the subtle changes in site selection criteria which were operative during the early historic period in north central Arkansas.

SUMMARY

The integration of database management, geographic information systems analysis, and exploratory data analysis can be used to provide structure to programs for cultural resource management and to increase the effectiveness with which we investigate the archeological resource base. The use of these tools, even in the absence of a comprehensive GIS database, can aid the planning process by directing investigations to sensitive areas and provide a basis for evaluating the relative significance of elements within the resource base. In addition, preliminary probability statements developed as a result of these applications can serve as a basis for long term management models which are subject to continual refinement with additional work.

AKNOWLEDGMENTS

I would like to take this opportunity to express our appreciation to William Goran and the staff at the Construction Engineering Research Laboratories, Lance McKee and David Schell of Masscomp computers, Carl Schuler and Scott Madry of the Institute for Technology Developments Space Remote Sensing Center and Doug Martin of the University of Washington's "S" project for their invaluable support. Without this support and their commitment to research this project and others currently in progress at the Arkansas Archeological Survey would not be possible. In addition, I would like to thank W. Fredrick Limp, Marylynn Kennedy and Karen Wagner for their review and comments on this manuscript.

REFERENCES

BUROUGHS, P. A., "Principles of Geographical Information Systems for Land Resources Assessment," Oxford Science Publications Monographs on Soil and Resources Survey No. 12, Clarendon Press, Oxford, 1986.

BECKER, R. A.; CHAMBERS, J.M., "S: An Interactive Environment for Data Analysis and Graphics," The Wadsworth Statistics/Probability Series, Belmont, California, 1984.

CHAMBERS, J. M.; CLEVELAND, W.S.; KLEINER, B.; TUKEY, P. A., "Graphical Methods for Data Analysis," The Wadsworth Statistics/Probability Series, Belmont, California, 1983.

CHERNOFF, H., The Use of Faces to Represent points in K-Dimensional Space Graphically," Journal of the American Statistical Association, volume 68, 1973, pp. 361-368.

HILLIARD, J.; RIGGS, J., "AMASDA Site Encooding Manual, Version 2.0," Arkansas Archeological Survey Technical Paper No. 1, 1986.

KVAMME, K, L., "Determining Empirical Relationships Between the Natural Environment and Prehistoric Site Locations: A Hunter-Gatherer Example," in "For Concordance in Archeological Analysis, edited by Carr, C., Westport Publishers, 1985.

KVAMME, K. L., "Computer Processing Techniques for Regional Modelling of Archeological Site Locations," Advances in Computer Archeology, volume 1, 1983, pp. 26-52.

LIMP, W.; PARKER, S.; FARLEY, J.; WADDELL, D.; JOHNSON, I., "An Automated Data Processing Approach to Environmental Resource Management for Military Installations," Arkansas Archeological Survey, submitted to U.S. Army CERL, 1987.

PARKER, S.; LIMP, W.; FARLEY, J., "Archeological Database Management as Conceptual Process," in For Concordance in Archeological Analysis, edited by Carr, C., Westport Publishers, 1985.

MARTIN, J., Managing the Database Environment, Prentice Hall, 1983.

MARTIN, J., Computer Database Organization, Prentice Hall, 1977.

TUKEY, J. W., "Exploratory Data Analysis," Addison-Wesley, Menlo Park, CA, 1977.

NEW CAPABILITIES FOR HYDROLOGIC ENGINEERING AND PLANNING

W.G. Brooner and M.C. Place
Earth Satellite Corporation, 7222 47th Street, Chevy Chase, MD 20815

A.D. Feldman
Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616

ABSTRACT

In the last decade, significant new tools have become available for planners, managers and scientists working in hydrologic engineering. Two new and significant tools are the widespread availability of spaceborne multispectral remote sensing systems, and the development of more sophisticated and less expensive micro computer work stations for both image processing and spatial data (GIS) analyses. This paper describes an evaluation of emerging remote sensing and spatial data capabilities and applications performed for the Corps of Engineers Hydrologic Engineering Center at Davis, California. It first surveys recent and planned spaceborne remote sensing systems providing data relevant to the hydrologic community. Next, integraded digital image processing and Geographic Information Systems (GIS) available today on microcomputers for applied hydrologic analyses are reviewed. Finally, the interaction of these capabilities is examined in the context of specific hydrologic engineering and planning tasks, ranging from real-time flood forecasting, to urban watershed modeling, to snow cover, evaporation, and soil moisture estimation.

INTRODUCTION

Access to accurate and timely information is a cornerstone in any decision making process. With multiple, often conflicting, demands on the use of a resource, it is mandatory that decision makers interface their information with increasingly sophisticated models that can realistically simulate the consequences of the array of strategies available to them. In the areas of water resources, the Hydrologic Engineering Center (HEC) has defined information requirements and provided simulation models used to support the decision making process, not only for the Corps of Engineers, but for water resource management organizations throughout the world.

Launch of the first Landsat satellite in 1972 was seen by many as an opportunity to revolutionize the collection and management of information for water and land resources. HEC was eager to investigate the potential of Landsat for hydrologic analyses. These investigations quickly revealed the interrelationship between this new digital format data plane and a computer-centered technology that would interface Landsat data with other data sets and then manage them for subsequent use in models. HEC was one of the first organizations to develop a Geographic Information System (GIS) that was called Spatial Analysis Methodology (SAM), and interface it with Landsat MSS remote-sensing-derived land cover information. That information was sufficiently accurate to define Snyder's unit hydrograph model with percent of imperviousness and the SCS curve number and lag method.

Despite the work of HEC and many other organizations, satellite remote sensing to support routine hydrologic investigations has not realized its potential. Part of the problem has been with the perceived limitations of the 80-meter and 30-meter resolution of the Landsat systems. Until the introduction of the PC-based image processing systems, a second problem has been ready access to the specialized equipment needed for interpretation and management of the satellite data. Perhaps an equally important problem has been in the management of Landsat data. Proponents of Landsat did not fully recognize that land cover was only one of several data sets required for the modeling of a watershed. Even though broad area land cover could be defined in a matter of hours, it still required many weeks to develop the soils, topography and socioeconomic information before the land cover could be "overlaid" on the other data sets. Thus, there has been little incentive to develop expertise in Landsat land cover utilization. The critical missing element needed for success has been an efficient, readily available, method for digitizing, merging and managing the numerous data sets what we currently call a "user-friendly" GIS.

Because of changes created by development of powerful, relatively inexpensive personal computers there are a number of GIS packages that provide many of the original HEC-SAM capabilities on desk-top workstations. Personal computer workstations can operate as "stand-alone" systems that allow the individual to literally take a 24"x36" digitizing tablet off the wall and quickly develop and manage the data sets required for an intermediate-sized watershed. At the same time, this personal computer workstation can be networked with remote computing capabilities to become a component in a regional system. Such as workstation capability is now readily available and can be a major driver in opening the door to widespread use of the benefits offered by digital format remote sensing.

New satellite remote-sensing systems now available overcome many of the 80-meter resolution problems of the original Landsat Multispectral Scanner (MSS) imagery. There are now satellites with 10-, 20- and 30-meter resolution, systems that provide detail that is sufficient for a large array of hydrologic analyses. When coupled with aircraft and ground-based sampling programs, the high-resolution satellite images can become very important sources of information. Fortunately, because of the current powers of GIS and digital-format remote sensing, we are at a point where the hydrologic community can really begin to integrate the array of data sources available. The term "fortunately" is used because the profession is at a point where fast, theoretically sound, accurate modeling is imperative. The Corps of Engineers is moving into a mode of operation that requires real-time assessments of the economic consequences of decisions that must be made during the passage of a flood. These decisions must be based on a thorough, quantitative understanding of watersheds, reservoirs and floodplains. Systems needed to translate these data into the required information are available, as well as information systems to allow hydrologists to simulate the consequences of a set of alternate strategies.

In October 1986, Hydrologic Engineering Center (HEC) contracted Earth Satellite Corporation (EarthSat) to conduct a study addressing several remote sensing technologies and spatial data applications relevant to HEC programs and missions. The study involved a series of related tasks as follows:

1. Investigate Emerging Remote Sensing Capabilities

2. Analyze Computing Environments

3. Review Improvements in Spatial Data Analysis Methods

4. Evaluate HEC options for Real-Time Estimates of Precipitation and Snow Cover

The first task includes an overview of new and newly operational remote sensing capabilities as they relate specifically to hydrology, particularly Landsat Thematic Mapper (TM), SPOT, AVHRR, and MOS-1. The roles of remote sensing and information systems as they relate to specific tasks involving HEC-1, HEC1-F, DWOPER, HEC-2, SID, DAMCAL and EAD are discussed along with the interactive role of remote sensing and geographic information system capabilities to a series of specific hydrologic engineering/planning tasks. Drawn from the experience of study team members, these tasks include:

1. Detect changes in land use which would alter a watershed's rainfall-runoff response. Use imagery to regionalize hydrologic parameters.
2. Use of Models of Estimate Runoff from Single Events and to Estimate geometry and Stage along a Stream Network
3. Real-Time Flood Forecasting and Estimating Stage-Damage Relationships
4. Quick Response Monitoring of Floods
5. Determining Interception and Depression Storage and Measuring Surface Water Distribution
6. Estimating Precipitation, Snow Cover and Snowmelt, Evapotranspiration, and Soil Moisture
7. Recent Developments in Snow Cover and Snow Water Equivalent
8. Potential Operational Benefit of Snow Cover Mapping
9. Remote Sensing of Snow Water Equivalent
10. Hydrologic Modeling of Urban Watersheds
11. Example of Hydrologic Modeling using ERDAS and a PC-Based GIS

Digital Image Processing included review of several related developments. First, a review of Computer Environment development focuses on the introduction of personal computers built around the Intel 80386 microprocessor which has dramatically altered the 32-bit workstation market. Second, geometric rectification characteristics of Landsat and SPOT data and requirements for image co-registration and georeferencing for large area mosaics are reviewed. And third, the application of statistical pattern-recognition techniques to multispectral remotely sensed data for the purpose of land cover classification has become common place; basic characteristics of land cover classification techniques are reviewed.

Many tasks which, in the past, were restricted to mainframe computers can now be executed quite easily on an off-the-shelf personal computer. In terms of processor speed, addressable main memory and amount of on-line disk storage, today's PC rivals mainframes in the not too distant past. Thus, it is practicable to build an image processing and geographic information system around personal computer technology.

Under the auspices of the HEC study, the report contains a benchmark evaluation of two commercially available PC-based image processing/GIS systems developed by ERDAS, Inc. and Terra-Mar Resources Information Services, Inc.

Finally, the study includes an evaluation of HEC's options for real-time estimates of precipitation and snow cover. Remote sensing tools now available to hydrologic applications extend beyond the well-demonstrated use of Landsat and SPOT, to include meteorological satellites, i.e., GOES, AVHRR and the NOAA polar orbitor, as well as the RADAP and NEXRAD meteorological radars.

The study outlines two sources for satellite-derived rainfall and snow-cover information and examines costs for each source in terms of a Corps' operational need. Compared sources include NOAA - via the Integrated Flash Flood Analysis (IFFA) Program, and EarthSat's CROPCAST™ system, both on a service basis and for system transfer and in-house implementation.

The study was conducted by a Consultant team of remote sensing, GIS, and hydrologic experts, including:

Mr. William Brooner EarthSat Corporation	-	Project Manager, Satellite sensor review, GIS applications
Mr. Michael Place EarthSat Corporation	-	Digital image processing, PC system evaluation
Dr. Robert Ragan University of Maryland	-	Information systems for hydrologic analyses, Hydrologic modeling studies
Mr. Donald Wiesnet Satellite Hydrology, Inc.	-	Snow cover and soil moisture, Quick response flood monitoring, Real-time precipitation and snow cover estimates
Mr. Earl Merritt EarthSat Corporation	-	Real-time precipitation and snow cover estimates
Mr. Morris Deutsch Satellite Hydrology, Inc.	-	Relevant Corps activities review
Mr. Arlen Feldman Hydrologic Engineering Center		Contracting Officier's Technical Representative

Dr. David Goldman - Review and guidance
Hydrologic Engineering
Center

Due to the depth and complexity of the study report, attempts to summarize content and findings while preserving information content in the proper context are not realistic. Interested persons may contact Mr. Arlen Feldman at HEC* for copies of the report which will be available for distribution after January 1988. EarthSat** will be pleased to respond to questions as they may arise.

---

* Hydrologic Engineering Center, U.S. Army Corps of Engineers, 609 Second Street, Davis, CA 95616 -- FTS 460-1748, (916) 551-1748, FAX (916) 756-8250

** Earth Satellite Corporation, 7222 47th Street, Chevy Chase, MD 20815, (301) 951-0104, FAX (301) 951-4077

A PILOT STUDY TO EVALUATE BACKWATER HABITAT ON THE GREEN RIVER USING AERIAL PHOTOGRAPHY AND GIS

M. J. Pucherelli, U.S. Bureau of Reclamation
P.O. Box 25007, Engineering and Research Center, D1524
Denver, Colorado 80225

R. C. Clark, J. N. Halls, and S. Wilds
Advanced Sciences, Inc.
P.O. Box 28007, Station 16
Lakewood, Colorado 80228

R. Williams, U.S. Bureau of Reclamation
P.O. Box 11568, UC-771
Salt Lake City, Utah 84147

ABSTRACT

In response to the proposed upgrade of Flaming Gorge Dam for the generation of additional hydro-electric power, a multi-agency environmental study was initiated in 1986. The studies were designed to gain an understanding of the needs of the endangered Colorado squawfish in order to enable the U.S. Fish and Wildlife Service to issue a biological opinion for the operation of Flaming Gorge Dam. This paper discusses the utility of remote sensing and GIS for identifying and mapping backwaters at different flows in the Green River. The U.S. Fish and Wildlilfe Service has concluded that backwaters in the Green River are important nursery habitat for young-of-the-year Colorado squawfish. To assess the trends of backwater habitat, three study sites were selected and monitored at four different flows. Large scale aerial photography was acquired concurrently with the flows. Aerial photographs were interpreted and digitized into a digital data base. Tabular data summaries and computer generated map plots were produced for each site. Results indicate that 1:4,000 scale color infrared aerial photography can be used successfully to determine backwater size and numbers on the Green River. The data suggest that numbers and total acres of backwaters are maximized at lower flows.

INTRODUCTION

In response to the proposed upgrade of the Flaming Gorge Dam which will provide for increases in hydro-electric power, an environmental study involving the U.S. Bureau of Reclamation (BR) and the U.S. Fish and Wildlife Service (FWS) was initiated in 1986. This study was designed to increase the understanding of the physical and biological requirements of the Colorado squawfish (Ptychocheilus lucius), an endangered fish species endemic to the Colorado River system. Information gained from these studies will enable the FWS to issue a biological opinion concerning the operation of Flaming Gorge Dam.

Following the installation of Flaming Gorge Dam, the abundance of native species including the Colorado squawfish has decreased. Based on extensive studies, the FWS has concluded that backwaters in the Green River are important nursery habitat for young-of-the-year Colorado squawfish. It is believed that maximizing backwater habitat in the Green River during the summer season may increase the survival rate of Colorado squawfish young-of-the-year.

This pilot study was developed to assess the feasibility of using aerial photography and GIS to evaluate changes in backwater habitat in relationship to varying flows in the Green River below Flaming Gorge Dam.

METHODS

Three study sites, each approximately 3 miles in length, were subjectively selected in areas known to contain important backwater habitat for the Colorado squawfish. The Split Mountain site was located from river mile 186 to 189.7; the Ouray site was located from 134.8 to 137.8; and the Willow Creek site was located from 117.8 to 121. River mile designations were taken from Evans and Belknap's Green River Wilderness, Desolation River Guide. River miles begin with 0 mile at the city of Green River, Utah. Figure 1 - Location Map, presents the location of each site along the Green River.

Four flows were chosen for examination: 1,500, 3,000, 3,500, and 4,000 cubic feet per second (cfs). Because of dam operation requirements, adverse weather, and unpredictable tributary flows, the actual flows studied were approximately 1,889, 3,119, and 4,359 cfs. When flows from Flaming Gorge Dam were stabilized, aerial photography was acquired for each study site. Two photographic scales were taken for comparison, 1:4,000 and 1:2,000. In addition, photographs were produced from color and color infrared film. These variables were tested to determine which combination of scale and film were best suited for the study's purposes.

Field trips were used to ground truth photography, to familiarize the photointerpreter with backwater delineation, and to place panel markers at specified distances to verify photographic scale. Ground truthing enabled the photointerpreter to determine the lower size limit of a backwater that was identifiable from aerial photography.

Aerial photographs were fitted with mylar overlays and interpreted for the following classes: open water, backwaters, isolated pools, sandbars, vegetated sandbars, and islands. Because the aerial photography was at a relatively large scale (1:4,000), it would have been difficult to transfer the interpreted classes to a standard 1:24,000 scale U.S. Geologic Survey quad, as the integrity of the larger scale data base would be lost. Therefore, to maintain interpretation accuracy, pseudomap bases of the same scale as the photography were created. Roads and other prominent features were delineated on photographs and compared to USGS maps to insure photo scale accuracy.

Following transfer of photointerpretation data to pseudomap overlays, the information was digitized into a Geographic Information System (GIS) utilizing Geographic Entry System (GES) software. Digitization was done in vector format using a Calcomp 9000 digitizing tablet linked to a Tektronix 4014 display screen. Software and peripherals are run by the HP 3000 Series III computer. Each study site was approximately 7.5 minutes by 7.5 minutes making the internal resolution of the computer 0.7 feet. The digitizing procedure was well within the photointerpretation error limits. Map plots and tabular summaries were produced for each site.

RESULTS AND DISCUSSION

Comparison of 1:4,000 and 1:2,000 scale photography indicated that the former is adequate for mapping backwaters to a minimum size of about 20 square

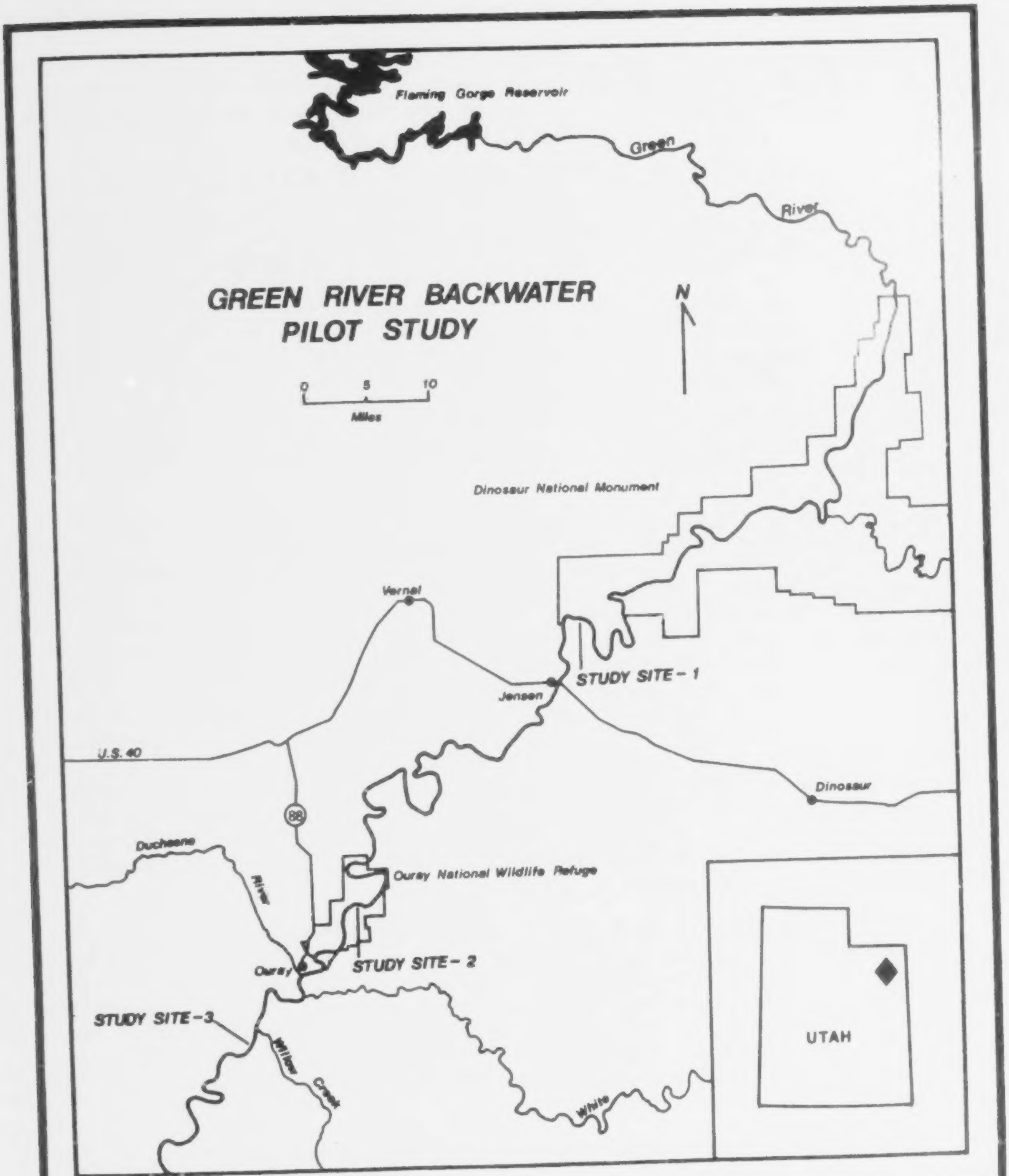

Flaming Gorge Reservoir
Green
River
GREEN RIVER BACKWATER PILOT STUDY
N
0 5 10
Miles
Dinosaur National Monument
Vernal
STUDY SITE - 1
Jensen
U.S. 40
Dinosaur
88
Duchesne
River
Ouray National Wildlife Refuge
Ouray
STUDY SITE - 2
STUDY SITE - 3
Willow
Creek
White
UTAH

FIGURE 1 - LOCATION MAP

meters. The additional information gained from using 1:2,000 scale photography is negligible and cost savings dictate the use of 1:4,000 scale photography.

Color infrared photography provided more detailed contrasts between water, sand, and sediment laden water than simple color photography. This allowed more precise and accurate backwater delineation and so reduced photointerpretation error.

Table 1 presents the number and acreages of backwaters and sandbars for each site. The general trend indicates maximum backwater area and number occurred at lower flows, with total acreage decreasing from 2.56 at 1,889 cfs, to 2.11 at 3,119 cfs, and to 2.10 at 4,359 cfs. The numbers of backwaters decreased from 37 at 1,889 cfs to 17 at 3,119 cfs, and then increased somewhat to 20 at 4,359 cfs. The trend varied at each site: at Ouray the largest number and acreage of backwaters occurred at 4,359 cfs, followed by the next largest number and acreages at 1,889 cfs; the Willow Creek site had the most backwater acreage at 3,119 cfs but the greatest number of backwaters at 1,889 cfs; while the Split Mountain site exhibited the maximum number and area of backwaters at 1,889 cfs. The situation at Ouray, where more and larger backwaters occurred at 4,359 cfs, may be attributable to higher, steeper, and more stable sandbars associated with vegetated islands.

In an effort to obtain a fourth set of photography, an interesting observation occurred. A flow of 1,500 cfs was requested in order to further define the range of flows needed to maximize backwater habitat. A fourth set of aerial photography was acquired on December 4, 1986, almost 3 months after the initial 1,889 cfs flow was acquired. The flow reading was nearly identical to the September 12, 1986, 1,889 cfs reading. After examining the photographs, it was noted that sandbar configuration and backwaters were significantly changed. Moreover, there was an average of approximately 30 percent loss in sandbar acreages calculated for the second 1,889 cfs flow (see Table 1). On the Ouray site, a large backwater near mile 135.2 was transformed into a side channel. The October Flaming Gorge Dam releases averaged 2,700 cfs with a high flow of 3,240 cfs and the November releases averaged 3,800 cfs with a high flow of 4,180 cfs. Apparently flows of this magnitude were sufficient to displace and degrade sandbars. As a result of these high flow events total backwater area increased 56 precent from 2.56 acres on September 12,1986 to 4.02 acres on December 4, 1986, although the total number of backwaters decreased.

These results indicate that 1:4,000 scale color infrared aerial photography can be successfully used to determine backwater size and numbers on the Green River. By studying various flow scenarios for a larger portion of the river, the optimum flow for producing backwaters may be predicted either for specific sites on the river, or the entire river section. Additionally, studies should be performed on the same sites in consecutive years to account for channel morphology changes resulting from high spring flows or annual releases from Flaming Gorge Dam.

The pilot study resulted in valuable information needed for planning future studies. It was apparent that data should be collected on the declining limb of the annual hydrograph in order to duplicate natural situations. Future remote sensing and GIS studies will focus on the lower end of the flow scenario, and more sites will be selected to reduce variability in the data. Future studies based on the pilot study will result in flow recommendations required to maximize backwaters in the Green River. These recommendations will be incorporated into the Flaming Gorge Endangered Fish Study.

TABLE 1 - ACREAGES AND NUMBERS OF BACKWATERS FOR THREE SITES AND FOUR FLOWS ON THE GREEN RIVER, UTAH

	Flows (cfs)							
Study Site	1889 09/12/86		3119 10/07/86		4359 10/15/86		1889 12/04/86	
	Acres	Number	Acres	Number	Acres	Number	Acres	Number
Split Mountain								
Backwaters	1.01	18	0.86	3	0.41	3	1.44	12
Sandbars	54.62	27	31.85	37	24.10	36	45.11	31
Ouray								
Backwaters	1.09	7	0.68	6	1.41	10	0.98	10
Sandbars	74.06	35	51.12	22	39.68	30	49.87	38
Willow Creek								
Backwaters	0.46	12	0.57	8	0.28	7	1.60	6
Sandbars	45.42	54	27.69	38	18.37	17	29.91	48
Totals								
Backwaters	2.56	37	2.11	17	2.10	20	4.02	28
Sandbars	174.10	116	110.66	97	82.15	83	124.89	117

THE IDENTIFICATION OF ARCHEOLOGICAL SITE PATTERNING THROUGH INTEGRATION OF REMOTE SENSING, GEOGRAPHIC INFORMATION SYSTEMS AND EXPLORATORY DATA ANALYSIS

W. Fredrick Limp
Arkansas Archeological Survey

There are a wide range of procedures broadly termed "remote sensing" which have been applied, quite usefully, to the study of archeological sites. The following paper will, however, only consider those data derived in digital format from multispectral scanners located on aircraft or satellite platforms. In particular, we will consider the various automated data processing methods which have been, or could be, used to extract archeologically relevant information from this MSS data.

HISTORICAL BACKGROUND

Following extensive use of photographic methods, the use of MSS derived digital data for the investigation of archeological site was discussed by Gumerman and Lyons in 1971. In their discussion of "scanner imagery", specifically infrared imagery, they note that there were many disadvantages, though the potential was great. In particular, they note the "exceedingly high cost" of data acquisition (1971:130).

In the late 1970s, digital data was used extensively, but almost exclusively as a derived photographic product which was subjected to visual examination (Table 1). The photographs were used to develop ecological/environmental zone maps. With few exceptions this data was Landsat MSS. One notable early exception to both patterns was the work of Morain et al. (1981a) which was apparently conducted in 1977 (Table 2). In this study eleven channel Bendix airborne MSS data was subjected to a suite of digital processing methods including principal components, maximum likelihood classification, and canonical analysis to develop site specific spectral classes.

Other digital processing projects have since followed (Table 1 and Table 2). A variety of techniques were used to determine either site specific spectral classifications or classifications of related landforms or the like. Methods include analysis of variance (Findlow and Confeld 1980), logistic regression (Custer et al. 1983, 1984, 1986; Holmer 1982; Wells et al. 1981), and principal components (Elstron et al. 1983; Inglis et al. 1984). The common classification methodology of maximum likelihood classification was used by Morain at al. (1981b), Hanlin (in Ebert and Lyons 1980) Baker and Sessions (1982), Mid-America Remote Sensing Center (MARSC) (1983), Sever (1983), Berta and Harrington (1984), Madry (1984), and Limp (1987a, 1987b).

TABLE 1. SELECTED SATELLITE (AND SATELLITE SIMULATOR) BASED STUDIES, BY YEAR PUBLISHED

	SENSOR	METHODS	GOALS	REFERENCES
1.	LANDSAT-MSS	VE	EZ	BROWN AND EBERT 1978
2.	LANDSAT-MSS	VE	EZ	EBERT 1978
3.	LANDSAT-MSS	VE	EZ	LYONS AND EBERT 1978
4.	LANDSAT-MSS	VE	EZ	CAMILLI 1979A
5.	LANDSAT-MSS	VE	EZ	CAMILLI 1979B
6.	LANDSAT-MSS	VE	EZ	CAMILLI AND SEEMAN 1979
7.	LANDSAT-MSS	VE	EZ	DRAGER 1980A
8.	LANDSAT-MSS	VE	EZ	DRAGER 1980B
9.	LANDSAT-MSS	VE	EZ	EBERT AND LYONS 1980
10.	LANDSAT-MSS	AV	CT	FINDLOW AND CONFIELD 1980
11.	LANDSAT-MSS	ML	EZ	HAMLIN (IN EBERT AND LYONS 1980)
12.	LANDSAT-MSS	LR	PM	WELLS ET AL. 1981 CUSTER ET AL. 1983 CUSTER ET AL. 1984 CUSTER ET AL. 1986
13.	LANDSAT-MSS	ML?	EZ	BAKER AND SESSIONS 1982
14.	LANDSAT-MSS	VE	EZ	DRAGER ET AL. 1982
15.	LANDSAT-MSS	PC	SS	LADE 1982
16.	LANDSAT-MSS	LR	PM	HOLMER 1982
17.	LANDSAT-MSS	VE	EZ	MCANAMY AND NELSON 1982
18.	LANDSAT-MSS	VE	EZ	EL SHAZLY 1983
19.	LANDSAT-MSS	PC	EZ	ELSTON ET AL. 1983
20.	TM(S)*	ML	SS	MID-AMERICA REMOTE SENSING CENTER 1983
21.	TM(S)**	DE, ML	SS, EDL	SEVER 1983
22.	LANDSAT-MSS	VE	EZ	BARISANO 1984
23.	LANDSAT-MSS	ML	EZ	BERTA AND HARRINGTON 1984
24.	LANDSAT-MSS	VE	EZ	CAMILLI 1984
25.	SPOT (S)	PC	SS	INGLIS ET AL. 1984
26.	LANDSAT-MSS	ML	SS	MADRY 1984
27.	LANDSAT-MSS	VE	EZ	BARISANO AND HALLY 1985
28.	TM	DE	EZ	EL BAZ 1986
29.	LANDSAT-MSS	VE	EZ	WANDSNIDER AND EBERT 1986
30.	TM	ML	SS, EZ	LIMP 1987b
31.	SPOT	ML	SS, EZ	LIMP 1987b

* 10 AND 30 M RESOLUTION
** 10 M RESOLUTION

KEY

METHODS

AV	analysis of variance
CA	Canonical Analysis
DE	Digital Enhancement
LR	Logistic and Linear Regression
ML	Maximum Likelihood
PC	Principal Components
VE	Visual Examination

GOALS

EDL	Edge/Linament Detection
EZ	Environmental/ecological zone
CT	Catchment Assessment
PM	Predictive Modeling
SD	Site Discovery
SS	Site Spectral Class

TABLE 2. SELECTED AIRBORNE SENSOR BASED STUDIES, BY YEAR PUBLISHED

SENSOR	IFOV/EFFECTIVE	METHHODS	GOALS	REFERENCE
BENDIX-MSS	3.75 FT.?	DE?	EDL	WILLIAMS (IN EBERT AND LYONS 1980)
SAR	15-20+ M	VE	SD	ADAMS ET AL. 1981a ADAMS ET AL. 1981b
BENDIX-MSS	3.75 FT.	DE, VE	EZ	MORAIN ET AL. 1981a
BENDIX-MSS	3.75 FT.	PC, ML	CA, SS	MORIAN ET AL. 1981b
ARIES-IR-MSS	1-2 M	DE, VE	SD	TABBAGH 1984
TIMS	5 M	DE, ML	SS, EDL	SEVER 1983
DAEDALUS-MSS	10, 2.5 M	ML	SS, EZ	LIMP 1987a

KEY

METHODS

AV	analysis of variance
CA	Canonical Analysis
DE	Digital Enhancement
LR	Logistic and Linear Regression
ML	Maximum Likelihood
PC	Principal Components
VE	Visual Examination

GOALS

EDL	Edge/Linament Detection
EZ	Environmental/ecological zone
CT	Catchment Assessment
PM	Predictive Modeling
SD	Site Discovery
SS	Site Spectral Class

Sensor type changed dramatically through time. With few exceptions, the projects reported through 1983 were all based on Landsat MSS. During this period a limited number of airborne scanner studies were reported. Since 1983, however, studies have reported utilizing TM, SPOT, DS1260, TIMS, SAR, and ARIES-IR. Through time there has been a steady increase in the spectral resolution available, including more bands of narrower wavelength, as well as significant improvements in the spatial resolution, from the 79 x 79 nominal Landsat MSS pixel to the now common SPOT 20 m and even higher resolution aircraft scanners. This improvement in spectral and spatial resolution has important consequences for archeological studies. In light of this, it is interesting that TM data does not appear as frequently in the literature as might be expected. The two earliest TM studies utilized the airborne Thematic Mapper simulator (MARSC 1983; Sever 1983). Landsat 4, the first satellite platform with TM capabilities, was launched July 16, 1982, with Landsat 5 following in March 1985. The initial SPOT sensor studies were also based on an airborne simulator. The satellite platform version was launched in early 1986.

The majority of these earlier studies focusing on application of digital image processing to archeological site discovery were properly pragmatic in their approach. That is to say, specific images were studied to determine if known archeological sites can be identified. It is appropriate, however, to consider the more fundamental issues of what we may expect the spectral and spatial properties of archeological sites to be, and then consider our methods in light of this knowledge. This is not to denigrate the earlier studies, but rather to consider the process from a different perspective. As we discuss the physical properties of sites and their spectral consequences, it must be recognized that there is a significant process of simplification at work. By any set of criteria archeological sites are extremely difficult to classify. In addition, even within a given site there may be significant variability.

Our first major topic of interest is the consideration of the issues pertinent to the direct discovery of spectral classification--"spectral signatures"--which identify archeological sites. As we will see there are numerous potential problems with such an approach. Some of these problems will be addressed in the next section of the report which considers the use of spectral data in the context of a comprehensive geographic information system.

Historically, a variety of non-digital techniques have utilized MSS data to improve the discovery of archeological sites (Table 1). Use of automated processing, however, is desirable (if it can be shown to be feasible) for a number of reasons (cf. Jensen 1986:6-7). These include, among others, the discovery of subtle variability not visually observable, the capability to process very large data sets rapidly, reproducibility, and the automated transformation of results into maps and summary tables.

Multispectral scanners record reflected and/or emitted radiation in the ultraviolet, visible, infrared, and microwave regions. If such sensors are to successfully identify archeological sites, then it must be the case that archeological sites have physical properties that emit or reflect measurable radiation which can quantitatively be discriminated from radiation from other, non-archeological locations. This discrimination can be due to the unique spectral properties of archeological sites or to contrast between the archeological site and its setting, either in spectral character or spatial patterning.

We must first consider what properties archeological sites may have. For this presentation we will focus on archeological sites found in the central United States--excluding sites, for example, with masonry construction. Sites have a wide range of variability, from isolated single artifacts to densely occupied villages with large earthen constructions.

Relevant physical properties which may be evidenced at an archeological site include:

1. phosphate enriched soils,
2. organically enriched soils,
3. differential soil compaction,
4. micro relief variation,
5. macro relief variation, and
6. regularity in edges or patterning in soil/vegetation.

With the exception of Number 6, none of these physical properties are likely to be directly observed by MSS, though the phosphate content may be closely and directly related to microtemperature variability. Regularities in edges or patterning may be observable visually (cf. Adams 1981; Barisano 1984; Miller 1981) and may be digitally enhanced (cf. Sever 1983). At this point, however, discovery of the spatial pattern itself requires human visual examination. The area of automatic spatial pattern recognition is a developing one, and we can be hopeful that automated procedures may become available in the future. While we are unlikely to directly observe the above physical properties, they do, however, have direct effect on a set of closely interlinked observable proxy properties. These include:

1. soil temperature,
2. vegetation type,
3. vegetation vigor, and
4. moisture retention.

All of these proxy properties have the potential to be observable with the appropriate MSS. We will return to this point in a moment. In addition to the issue of potentially observable properties, the second issue of interest is the relative differentiation or contrast of these properties with respect to the areal context in which they appear. In other words, if archeological locations have potentially similar temperature/vegetation/

moisture properties as do non-archeological locations, it will be impossible to isolate the archeological site from its background. This situation can be considered as covariation of environmental circumscription and viable locations. This may be illustrated through the following examples. In much of the Mississippi River Valley environmental conditions circumscribe the candidate locations for human occupation. In brief, many of these locations are on slight natural levee crests. These crests are frequently comprised of better drained more sandy soils, surrounded by dense poorly drained backswamps. In such settings, archeological site proxy properties may have good differentiation with respect to the other candidate locations within the spectral range.

For a contrast we can consider the forested uplands of the Ozark Mountain area. Here environmental circumscription in based, among other things, on accessibility to water and relative flatness. All unoccupied candidate locations will tend to have spectral properties much like the archeological sites.

Archeological sites also vary on dimensions of intensity of occupation and size. A very schematic representation of these relationships are illustrated in Figure 1. Again, it must be emphasized that this significantly simplifies a very complex reality. There is no doubt substantial overlap between these idealized categories.

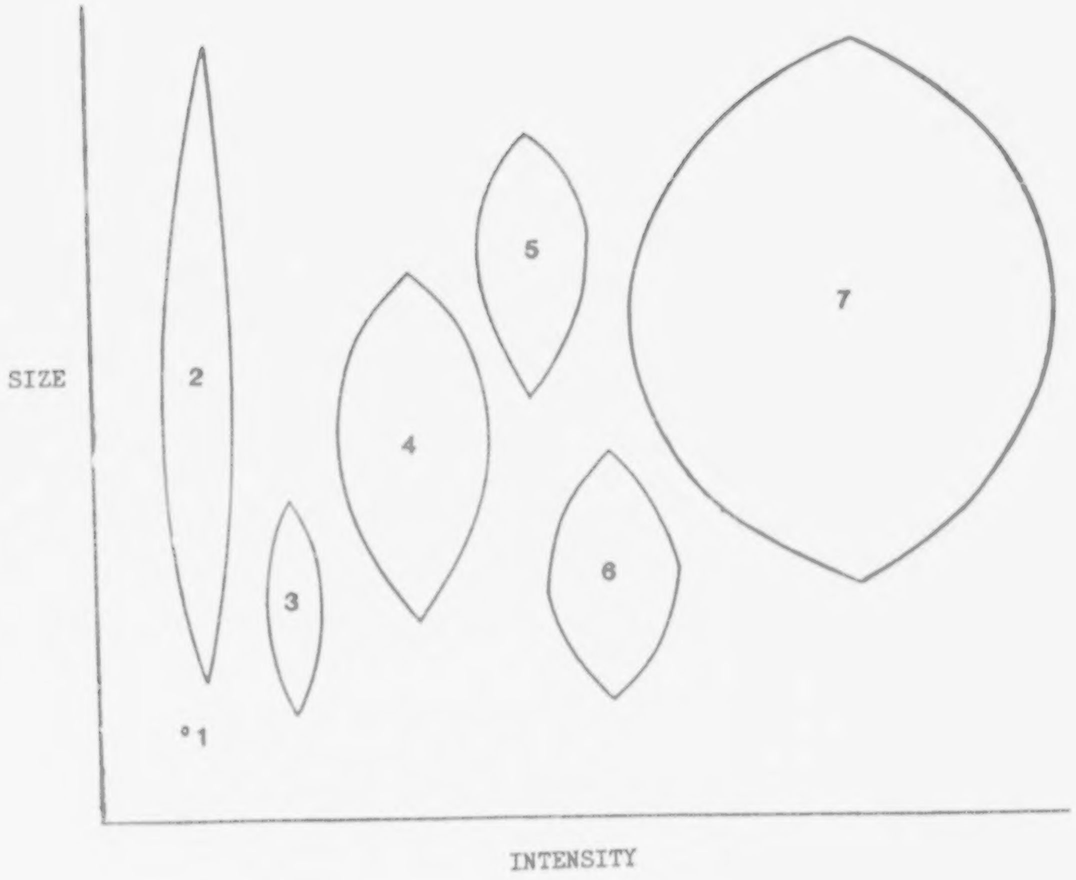
SPECTRAL AND SPATIAL PROPERTIES OF MSS SYSTEMS

Having briefly reviewed the properties of archeological sites and their spectral and spatial characteristics, we turn now to a consideration of similar properties of the various MSS systems. Figure 2 presents the spectral bands of six common sensors in the visible to mid-infrared ranges, while Figure 3 presents a similar comparison for the far (or "emissive") infrared. Not shown is the microwave region with various radar sensors.

For direct measurement of thermal properties the TIMS sensor is clearly superior. It not only focuses on a broad range in the far infrared, it also has more channels and generally superior thermal sensitivity. It nominally has a sensitivity of 0.1°C. Not only is direct thermal evaluation possible on soil, but the thermal sensitivity also permits the monitoring of stress in plants, which is related to other proxy variables noted above (Anderson 1983; Pallucino and Meeks 1985; Gillespie et al. 1984; Sever 1983). The other sensors have reduced capabilities in this area, but as Tabbagh (1984) has shown, these sensors are not without usefulness.

Bands 5 and 7 of the TM sensor have good potential for measurement of leaf water content (Gausman et al. 1978), which is obviously related to the proxy properties of vigor and moisture. In addition to direct measurement, a variety of interband manipulations appear to address the proxy properties. In particular, transformations of the first six TM bands

FIGURE 1. PROTOTYPICAL RELATIONSHIP BETWEEN SIZE AND INTENSITY OF OCCUPATION FOR SEVEN SITE TYPES



1. isolated artifact
2. transportation route
3. single occupation, specialized activity
4. multiple occupation, specialized activity
5. agricultural field
6. seasonal occupation, habitation
7. permanent occupation, habitation

FIGURE 2. COMPARISON OF VISIBLE-MID-INFRARED SPECTRAL BANDS OF SELECTED MULTISPECTRAL SCANNERS

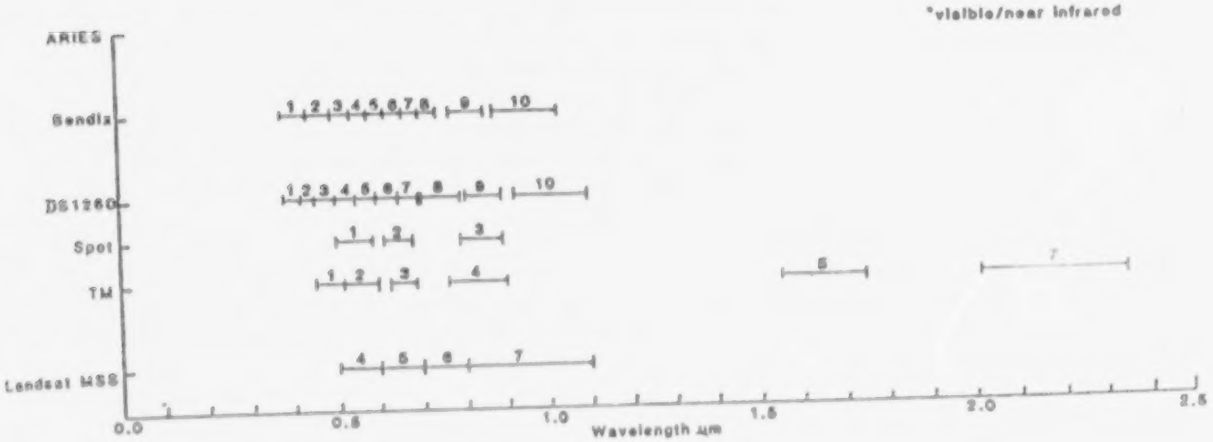
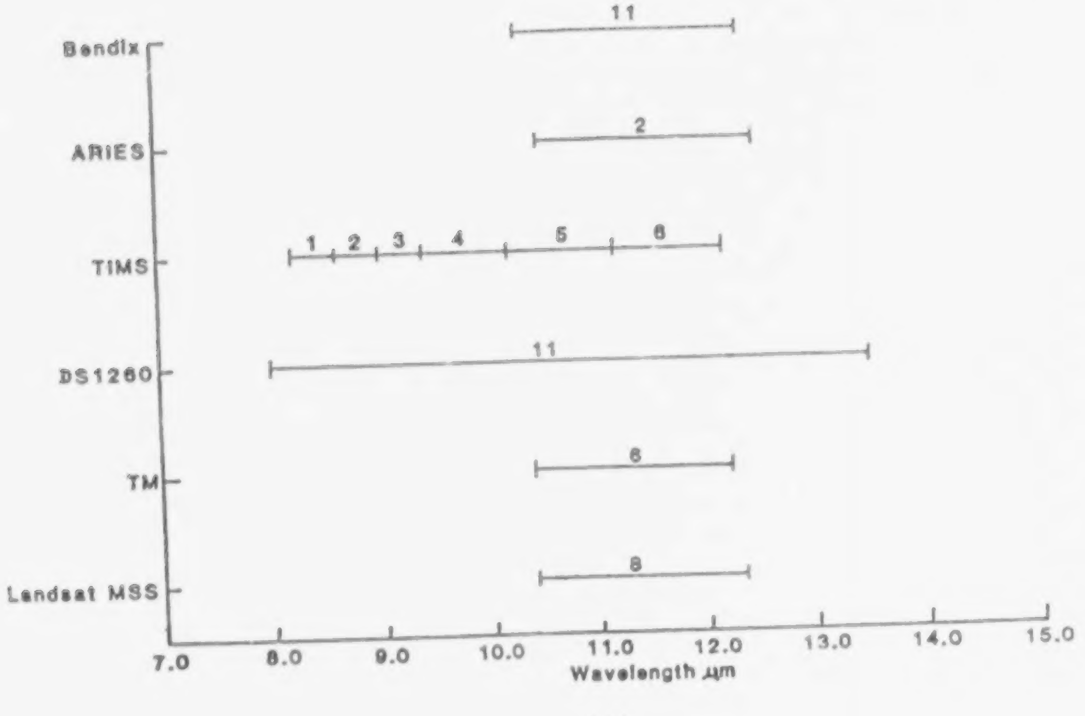


FIGURE 3. COMPARISON OF FAR (EMISSIVE) INFRARED SPECTRAL BANDS OF SELECTED MULTISPECTRAL SCANNERS



utilizing techniques developed by Crist and Cicone (1984), similar to the tasseled cap transformation of Kanth and Thomas (1976), are very effective in isolating subtle soil moisture content differences. Vegetation vigor can also be evaluated utilizing similar methods. The Bendix and DS1260 airborne sensors have bands which are quite similar to the first four TM bands, but they do not have comparable bands to TM 5 and 6. As a result, discrimination will likely be reduced for these sensors, other things being equal, which as we shall see they are not.

The nominal spatial resolution of the various satellite sensors is well known. Aircraft scanner resolution is, of course, a function of the altitude and the IFOV. Table 2 indicates the effective resolution for the archeological studies reported.

Unfortunately, there is substantial misunderstanding of the nature of sensor resolution (Forshaw et al. 1983). Linear features such as roads, which are smaller than the nominal IFOV, are often visible on MSS. With the exception of such features, however, the equivalent photographic resolution of MSS data is commonly less than the quoted IFOV. Landsat MSS has an IFOV of 79 m, but the equivalent photographic resolution is on the order of 200 m (Forshaw et al. 1983).

The situation is made more complex when the concern is with the discovery of spectral classes. Jensen (1986:32-33) indicates that, as a useful rule of thumb for forestry and agricultural applications, an area of interest must be of some 60 IFOVs to be classified with acceptable accuracy. The results of applying this "rule" to archeological sites are illustrated in Table 3. The nominal diameter reflects the size of the site if it was circular.

In Table 4 we present the size distributions of archeological sites in Arkansas. This data is obtained from the AMASDA database (Hilliard and Riggs 1986). This database contains extensive information on the more than 20,000 known archeological sites in the state. One observation which is made is the site's size class. Size class data is available for roughly one-half of the sites, and class limits are those in the database. Table 5 displays similar information, but only for those sites which have the presence of midden deposits reported. Table 6 presents similar data for sites where aboriginal mounds are reported. These latter two categories were chosen as indicating those sites with more intensive occupational evidence.

The potential spatial limitations of many of the MSS are evident when we compare Table 3 with 4, 5 and 6. Based on Jensen's "rule", something less than 2% of the sites would be accurately classified by Landsat MSS. The number would increase to something less than 6% for TM and 12% for SPOT. Even at 10 m resolution, the airborne scanners would be unable to accurately classify more than one-half of the sites.

TABLE 3. EFFECTIVE MINIMUM SITE SIZE BASED ON 60 IFOV'S TO ALLOW ACCEPTABLE CLASSIFICATION ACCURACIES

SENSOR	NOMINAL DIAMETER	NOMINAL AREA
LANDSAT-MSS	581 m	26.5 ha *
TM	262 m	5.4 ha
SPOT-MSS	175 m	2.4 ha
DS1260 BENDIX-MSS TIMS CAMS	22 M - 87 m	0.04-0.6 ha

* BASED ON REFORMATTED PIXEL SIZE OF 4424 M^2

TABLE 4. SIZE CLASSES FOR ARCHEOLOGICAL SITES IN ARKANSAS (SOURCE: AMASDA DATABASE)

SIZE CLASS	COUNT	PERCENT
GREATER THAN 10 ha	263	2.0
4.0 - 10.0 ha	535	4.1
2.0 - 4.0 ha	814	6.2
0.5 - 2.0 ha	2911	22.3
0.1 - 0.5 ha	3995	30.7
0.01 - 0.1 ha	2751	21.1
0.001 - 0.01 ha	929	7.1
LESS THAN 0.001 ha	838	6.4
	13,036	99.9

TABLE 5. SIZE CLASSES FOR ARCHEOLOGICAL SITES IN ARKANSAS WHERE MIDDEN DEPOSITS ARE REPORTED AS PRESENT (SOURCE: AMASDA DATABASE)

SIZE CLASS	COUNT	PERCENT
GREATER THAN 10.0 ha	38	4.4
4.0 - 10.0 ha	66	7.6
2.0 - 4.0 ha	87	10.0
0.5 - 2.0 ha	261	29.9
0.1 - 0.5 ha	238	27.3
0.01 - 0.1 ha	144	16.5
0.001 - 0.01 ha	34	3.9
LESS THAN 0.001 ha	5	0.6
	873	100.2

TABLE 6. SIZE CLASSES FOR ARCHEOLOGICAL SITES IN ARKANSAS WHERE MOUNDS ARE REPORTED AS PRESENT (SOURCE: AMASDA DATABASE)

SIZE CLASS	COUNT	PERCENT
GREATER THAN 10.0 ha	38	7.0
4.0 - 10.0 ha	55	10.1
2.0 - 4.0 ha	61	11.2
0.5 - 2.0 ha	150	27.6
0.1 - 0.5 ha	157	28.9
0.01 - 0.1 ha	71	13.1
0.001 - 0.01 ha	11	2.0
LESS THAN 0.001 ha	0	0.0
	543	99.9

Unfortunately, many of the 13,000 sites may consist of only a light surface scatter of occupational materials. If we consider those site which are likely to have relatively intense evidence, a somewhat better picture emerges with respect to percentage, but the total number declines. For sites with midden, reported Landsat-MSS would accurately classify somewhat less than 4%, TM also doubles its percentage with somewhat less than and SPOT increases to slightly under 22% accurately classified. Even at 10 m resolution, however, almost one-half (48.3%) of the sites still would not be accurately classified.

Sites with mounds reported are generally larger than those with midden reported, with comparable increases in sites accurately classified. However, at the 10 m resolution, 44% of the sites, even those with mounds, still fall below the threshold for accurate classification. Again, we must emphasize that those above the accurately classified threshold only encompass a few hundred sites out of the statewide total of more than 20,000. These numbers should serve to indicate some of the substantial limitations which are faced in development of direct spectral classes.

We must also note a number of caveats to the quality of the data and to the rather simple logic being applied. While the various size class information is useful, it is clearly limited, as all such data is, by the wide diversity of recorders and record keeping. The precision of the numbers belie the actual fuzziness of the data. In particular, the observation of midden presence/absence is a judgement call often based on limited data. It may be the case that the actual numbers are at substantial variance, probably larger. Size determinations are also a notoriously slippery measure. Jensen's "rule" is also less binding than many. Important factors not specifically considered are within site variability, site shapes including boundary regularity, and, as noted before, contrast with background.

An independent measure of the necessary spatial resolution needed can be obtained from the assessments by Welch (1982) on IFOV for various land-use classifications. He indicates that Level II classifications require an IFOV of ca 2.0-2.5 m, while Level III requires an IFOV of less than 1 m and Level IV an IFOV of under 0.5 m. Level II classifications include very broad groupings, e.g. forest land is divided into deciduous and evergreen, wetlands are divided into forested and nonforested. Archeological site classification would appropriately fall within Levels III or IV. Botkin et al. (1984) (cf. also NASA 1983) have presented information on spatial resolution and the level of detail needed for vegetation mapping. Four levels of interest are III (Biome), IV (Region), V (Plot) and VI (Sample Site).

Needed resolution for biome inventory is 80-30 m IFOV, which includes Landsat MSS and TM. Region inventory requires the IFOV range of 30-3 m, with TM and SPOT included at the upper range and aircraft scanners at the lower. Plot inventory, probably most comparable to site mapping, is described as requiring an IFOV of 3-1 m. Such resolutions are currently achievable only by relatively low flying aircraft MSS, though new satellite based sensors from the Soviet Union and others will achieve these levels. Sample site inventory can only be obtained by direct on-site surface measurements.

Bringing all this data together, it is evident that Landsat-MSS should not be effective for archeological site discovery through spectral classification. This is not surprising. What is more unsettling is the strong potential that TM spatial resolution may be such that only the larger, more intense occupational locations fall within the sensor's range. SPOT extends this range, but its improvements in spatial resolution are somewhat offset by reductions in the number of its spectral bands. In particular, the absence of bands in the infrared reduce the sensor's effectiveness for archeological site discovery.

We can now turn to a review of previous studies to determine if the above suppositions are borne out in practical applications.

LANDSAT-MSS RESULTS

In reviewing earlier studies (Tables 1 and 2), the inability of Landsat MSS to determine spectral classes for all but the largest archeological sites is supported. With the exception of Lade (1982), no researcher has reported success in this area.

TM RESULTS

Of the four TM projects, two utilized aircraft simulators (MARSC 1983 and Sever 1983). El Baz's work (1986) did not involve the use of spectral classification. Limp's (1987b) involved satellite data.

In the MARSC study, both 10 and 30 m data was considered. Aircraft flightlines were directed to the locations of substantial archeological sites in the Ohio River Valley, including Kincaid, Shawnee and Twin Mounds. Sites ranged in size from under 2 to more than 50 ha and most included both extensive occupational evidence (e.g. "dark midden") and earthen mounds.

One site studied, Kincaid, is more than 1.5 km in length and is described in the report as the "second or third largest site in the southeastern U.S." (1983:28). No distinct archeological signatures for any of the sites were determined utilizing the 30 m data. No distinctive archeological signatures were determined for the 10 m data, but "as successive classification schemes were run, the classes which depicted features associated with the various sites were more limited after each run" (1983:39). The authors concluded that "having such information could eliminate the possibility of a total field survey and direct the archeologist to specific areas of high probability. TMS data offer indirect evidence of possible site localities" (1983:39).

Methods involved the use of unsupervised maximum likelihood classification. Within class, classifications were performed, as well as supervised spatial classifiers. All classifications were performed on raw data corrected for pixel dropout and cross scene illumination. In Flightline 1 channels 2, 3 and 5 were eliminated as were channels 6 and in
Flightline 2.

In considering the results of this study with respect to our previous discussion, it would appear that the results were less successful than anticipated.

While the study was well structured and thorough, there was no classification focusing involving transformed and/or ratioed data. Data was obtained April 11, 1982, with grasses in early growth, forest cover with some leafed out and some leafless, and there was wide variability in agricultural exposures. While the time chosen allowed bare earth exposures, it may be the case that vegetation vigor/growth and moisture characteristics may be more pronounced later in the growing season.

Similar techniques were used by Sever (1983) who examined only 10 m data. These data were acquired over Chaco Canyon, New Mexico, ten days before the Ohio Valley flight. The particular object of interest in the Chaco area was the location of the prehistoric roadways known in the area. Automated signature development was unsuccessful. As was the case in the Ohio Valley study, no transformations were performed, however, ratioing was performed for purposes of visual enhancement. It is not clear from the report if an attempt was made to develop spectral classes for archeological resources other than the roadways. A number of sizeable properties are present in the area. Sever concludes "for immediate archeological feature detection, the TMS demonstrated the best utility in the thermal band (10.3-12.3 um) for detecting the location of the prehistoric Chacoan roads. However, TMS data can be used to develop classifications which can be compiled with ancillary data sources into a geobased reference system. Interactive processing of these various data planes can be used to develop predictive models for aboriginal occupations, farming and travel routes" (1983:22).

TM work by Limp (1987b) is underway and cannot be reported in detail here. It involves midyear data acquisition (July 1985) in Central Arkansas. Some 600+ known archeological sites are located within the scene. Analysis includes transformations in the classification effort.

SPOT RESULTS

Three areas will be discussed which have been examined utilizing the SPOT sensor. One in Bandelier National Monument was based on SPOT simulator data acquired June 19, 1983 (Inglis et al. 1984). The second two are located in Arkansas.

The Bandelier data was analyzed utilizing standard unsupervised classification methods and a maximum likelihood classifier. Raw data, principal components and a number of interband ratios were examined. Eighty six archeological sites were located within the study area. The size of the study area was not reported.

Three suites of classification for raw data, principal components, and ratios were developed generating 26, 27 and 27 classes respectively. One of the suites of classes, which one was not specified in the report, produced favorable site related classes.

Out of the 26+ classes, classes 2 and 7 represented only 25% of the area, but accounted for 45% of the sites. As the authors state, "This, we feel, is significant. When the two classes are mapped, they do not correspond exactly to either of the previously generated vegetation cover or soil maps. This implies that archaeological sites may have a relationship to a spectral class and possibly to a cover type . . ." (Inglis et al. 1984:78). In their summary, however, the authors propose that, in the Southwest, archeological sites have characteristics that "are more or less spectrally identical to the immediate surroundings. Rather than spend much effort attempting to refine methods for actually seeing the physical manifestations of past people, archeologists might better . . . devise ways of using the analysis of environmental variables . . . in the prediction of occurrence, visibility and integrity of archaeological materials" (1984:80-81).

The two Arkansas areas are within the same SPOT scene. One area, Lee Creek, is in the Ozark uplands north of Fort Smith, Arkansas, while the second, Frog Bayou, is in the Arkansas River Valley.

The initial Frog Bayou study area encompassed some 3,437 hectares between the mouths of Frog Bayou and the Mulberry River in the Arkansas River Lowlands (Limp 1987b). The area included largely floodplains and terraces of the major river but nearby uplands were included. Following initial pre-screening, all three bands of a July 7, 1987, SPOT image were subjected to an unsupervised maximum likelihood classification. Image processing was performed on the Arkansas Archeological Survey's MASSCOMP 5600 system with NASA-ERL ELAS software (Graham et al. 1984). ELAS modules SRCH and MAXL were utilized. Eighteen classes were identified. The classified image was georeferenced in ELAS utilizing the nearest neighbor method. The resulting georeferenced image was transferred to the GRASS geographic information system (Goran et al. 1986) utilizing GRELAS software developed by the Arkansas Archeological Survey (Farley et al. 1987). Archeological site locations were digitized from USGS 7.5 minute quads utilizing GRASS's MAP_DEV modules. The archeological site data layers were then compared to the georeferenced image utilizing a number of GRASS analysis modules. Seventy-five archeological sites were present and represented 1,943 cells, or some 77.7 ha total. Site sizes ranged from more than 32 ha to less than 0.1 ha. In total, archeological evidence represented some 2.3% of the study area. It is significant to note that in this study archeological sites were not treated as individual points but were themselves areal features. Isolated artifacts, though recorded, were not included in this study.

Comparison of the distribution of cells (20 m x 20 m) without archeological sites and those with occupational evidence is shown in Table 7. In the following table (Table 8) the cell counts are converted to percentages. The first indicates the spectral class, Column 2 represents the cell counts or relative occurrence of the class in the area, while the third column indicates the cell counts or percentage of total site area within the spectral class. For the cell tables the fourth column is the total cell counts for the class. Note that class 0 is "no data" and class 1 is a "dummy class", needed for mapping purposes. Its values should be ignored. We can expect site percentages (Column 3) to be similar to the overall percentages (Column 2) if the site distribution was random with respect to the class. More substantive statistical comparisons are, of course, possible and are reported in Limp (1987b). In overview, however, we can see that site occurrences are high in classes 2, 4, and 7. Collectively, these represent exactly 50% of the sites, but only 29.9% of the area. These figures compare favorably with those of Inglis et al. (1984) discussed above. The second SPOT study area was in an upland stream valley along Lee Creek in western Arkansas. The data was derived from the same SPOT image and processed in a similar manner. The Lee Creek study area encompasses 3,030 ha. Fifty-six archeological sites are reported covering some 100.4 ha, representing 3.3% of the total area. The entire study area has been subjected to intensive pedestrian survey, and, thus, we accurately know where sites are, as well as where they are not. Sites in the area range from a maximum of 11.2 ha to less than 0.1. Only 13 of the sites are larger than 60 IFOVs, though five are only just slightly smaller. Sites in the area are also generally ephemeral in nature, with midden evident at relatively few sites even in extensive testing.

A total of 21 categories were developed by the classification. Cell counts for each class for the total area and for those with sites are shown in Table 9. The following table (Table 10) indicates the relative percentages. Sites are over-represented in classes 4, 13 and 17. Other classes also had higher than expected frequencies, e.g., Class 21, but the actual cell counts are quite small and may be simple sample error. Sites in the three classes represent 34.2% of the sites and only 19.3% of the area.

The relative lack of success is to be expected. Sites in Lee Creek are much more ephemeral than those of Frog Bayou, though they are larger on average. Lee Creek's sites average 1.8 ha, while Frog Bayou's averages 1.0 ha. The size advantage would appear to favor the Lee Creek area. This advantage is, however, offset by the more intense occupation in Frog Bayou, and most importantly, by the increased circumscription of Frog Bayou. Candidate locations in the Frog Bayou study area are those of large river

TABLE 7. CELL COUNTS FOR FROG BAYOU. COLUMN 1 IS SPECTRAL CLASS, COLUMN 2 COUNTS FOR ENTIRE AREA EXCLUDING SITE CELLS, COLUMN 3 CELLS WITH SITES, COLUMN 4 TOTAL CELLS.

CLASS	CELLS WITHOUT SITES	CELLS WITH SITES	TOTAL CELLS
0	0	0	0
1	630	0	630
2	8905	287	9192
3	8810	95	8905
4	4694	227	4971
5	13628	212	13840
6	1941	27	1968
7	11154	408	11562
8	1010	5	1015
9	11573	162	11735
10	439	30	469
11	11	0	11
12	200	0	200
13	2648	105	2753
14	2276	95	2371
15	3841	24	3865
16	11	0	11
17	10802	211	11013
18	962	5	967
19	454	0	454
TOTAL	83989	1943	85932

TABLE 8. RELATIVE FREQUENCIES FOR TOTAL AREA AND SITE AREAS FOR FROG BAYOU. COLUMN 1 IS SPECTRAL CLASS, COLUMN 2 THE FREQUENCY OF THIS CLASS FOR THE ENTIRE AREA, COLUMN 3 THE FREQUENCY OF CELLS IN THIS CLASS WITH SITES.

CLASS	% of AREA REPRESENTED	% OF TOTAL SITE AREA
0	0.00	0.00
1	0.73	0.00
2	10.70	14.77
3	10.36	4.89
4	5.78	14.26
5	16.11	10.91
6	2.29	1.39
7	13.45	21.00
8	1.18	0.26
9	13.66	8.34
10	0.55	1.54
11	0.01	0.00
12	0.23	0.00
13	3.20	5.40
14	2.76	4.89
15	4.50	1.24
16	0.01	0.00
17	12.82	10.86
18	1.13	0.26
19	0.53	0.00
TOTAL	100.00	100.00

TABLE 9. CELL COUNTS FOR LEE CREEK. COLUMN 1 IS SPECTRAL CLASS, COLUMN 2 COUNTS FOR ENTIRE AREA EXCLUDING SITE CELLS, COLUMN 3 CELLS WITH SITES, COLUMN 4 TOTAL CELLS.

CLASS	CELLS WITHOUT SITES	CELLS WITH SITES	TOTAL CELLS
0	47309	0	47309
1	16	20	36
2	10603	897	11500
3	2869	123	2992
4	2977	492	3469
5	1	0	1
6	547	2	549
7	95	22	117
8	8	3	11
9	25	0	25
10	0	0	0
11	0	0	0
12	20	3	23
13	439	78	517
14	0	0	0
15	5321	501	5822
16	0	0	0
17	1194	289	1483
18	897	32	929
19	815	14	829
20	47	0	47
21	26	13	39
22	30	22	52
TOTAL	73239	2511	75750

TABLE 10. RELATIVE FREQUENCIES FOR TOTAL AREA AND SITE AREAS FOR LEE CREEK COLUMN 1 IS SPECTRAL CLASS, COLUMN 2 THE FREQUENCY OF THIS CLASS FOR THE ENTIRE AREA, COLUMN 3 THE FREQUENCY OF CELLS IN THIS CLASS WITH SITES.

CLASS	% of AREA REPRESENTED	% OF TOTAL SITE AREA
0	--	--
1	--	--
2	40.49	35.72
3	10.53	4.90
4	12.21	19.59
5	0.00	0.00
6	1.93	0.08
7	0.41	0.88
8	0.04	0.12
9	0.09	0.00
10	0.00	0.00
11	0.00	0.00
12	0.08	0.12
13	1.82	3.11
14	0.00	0.00
15	20.50	19.95
16	0.00	0.00
17	5.22	11.51
18	3.27	1.27
19	2.92	0.56
20	0.17	0.00
21	0.14	0.52
22	0.18	0.88
TOTAL	100.00	100.00

alluvial settings, dominated by natural levees, terrace edges and the like. In Lee Creek, though there is floodplain development, candidate locations are much less circumscribed and not generally correlated with contrasting backgrounds.

This issue is most eloquently illustrated in the Green Tree study area (Limp 1987a). This study area is located in the White River Valley south of Newport, Arkansas. Data was obtained by a DS1260 with an IFOV of 10 m. Data was acquired by EPA aircraft under contract to the U.S. Army Corps of Engineers. Data was processed in a similar manner to the previously discussed SPOT, in addition to preprocessing needed for aircraft imagery. For the initial study, only three bands were selected (3, 5 and 7).

The study area is largely wetlands with natural levee crests along the White River and terraces to the west. A total of 1,480 ha were considered, of which 0.85 ha were archeological sites. Only limited survey has been conducted, and only four sites were reported. These represented less than 0.6% of the area. These small numbers mean the results are to be viewed with caution. As illustrated in Tables 11 and 12, archeological sites are common in spectral classes 4, 5 and 10. These represent 27.8% of the area, but 69.9% of the site cells.

In comparison with the other study areas, we have a superior IFOV and a circumscribed environmental situation. As we anticipated, our capability to accurately classify archeological sites is substantially improved.

The Arkansas results are based on only the most fundamental classification actions. No ratioing or transformations were performed. Continuing research will be adding these further techniques.

REMOTE SENSING AND GIS

While the results reported here are positive, we must still recognize that much is to be desired if remote sensed imagery is to be effectively used in archeological research and management. Not only is more accurate classification needed, but, even if perfectly accurate, remote sensing imagery alone can only assist us in locating sites. For both managerial and research purposes it is essential to be able to increase our understanding of the processes which generated the observed patterns. In order to improve our accuracy and to address these processual issues, the remote sensed data needs to be integrated into a comprehensive automated data processing environment, which includes archeological site/project databases, environmental data in a geographical information system and techniques such as exploratory data analysis, "EDA", to assist in determining complex multivariate patterning. Such a framework, excluding the remote sensing component, has been proposed by Parker et al. (1986) and Limp et al. (1987). We have previously noted Sever (1983) and Inglis et al.'s (1984) recommendations that remote sensing could be most effectively utilized in a GIS setting. In the larger area of resource management,

TABLE 11. CELL COUNTS FOR GREEN TREE. COLUMN 1 IS SPECTRAL CLASS, COLUMN 2 COUNTS FOR ENTIRE AREA EXCLUDING SITE CELLS, COLUMN 3 CELLS WITH SITES, COLUMN 4 TOTAL CELLS.

CLASS	CELLS WITHOUT SITES	CELLS WITH SITES	TOTAL CELLS
0	0	0	0
1	485	0	485
2	17944	69	18013
3	4976	46	5022
4	13944	262	14206
5	20936	235	21171
6	16050	9	16059
7	3615	39	3654
8	19306	0	19306
9	4460	7	4467
10	5759	96	5855
11	7984	1	7985
12	916	19	935
13	94	0	94
14	5496	0	5496
15	4895	0	4895
16	403	0	403
17	11450	40	11490
18	173	0	173
19	960	0	960
20	1501	3	1504
21	141	7	148
22	95	0	95
23	13	0	13
24	3	0	3
25	365	15	380
26	1144	1	1145
27	374	0	374
28	82	0	82
29	3616	0	3616
30	0	0	0
TOTAL	147180	849	148029

TABLE 12. RELATIVE FREQUENCIES FOR TOTAL AREA AND SITE AREAS FOR GREEN TREE. COLUMN 1 IS SPECTRAL CLASS, COLUMN 2 THE FREQUENCY OF THIS CLASS FOR THE ENTIRE AREA, COLUMN 3 THE FREQUENCY OF CELLS IN THIS CLASS WITH SITES.

CLASS	% of AREA REPRESENTED	% OF TOTAL SITE AREA
0	0.00	0.00
1	0.33	0.00
2	12.17	8.13
3	3.39	5.42
4	9.60	30.86
5	14.30	27.68
6	10.85	1.06
7	2.47	4.59
8	13.04	0.00
9	3.02	0.82
10	3.96	11.31
11	5.39	0.12
12	0.63	2.24
13	0.06	0.00
14	3.71	0.00
15	3.31	0.00
16	0.27	0.00
17	7.76	4.71
18	0.12	0.00
19	0.65	0.00
20	1.02	0.35
21	0.10	0.82
22	0.06	0.00
23	0.01	0.00
24	0.00	0.00
25	0.26	1.77
26	0.77	0.12
27	0.25	0.00
28	0.06	0.00
29	2.44	0.00
30	0.00	0.00
TOTAL	100.00	100.00

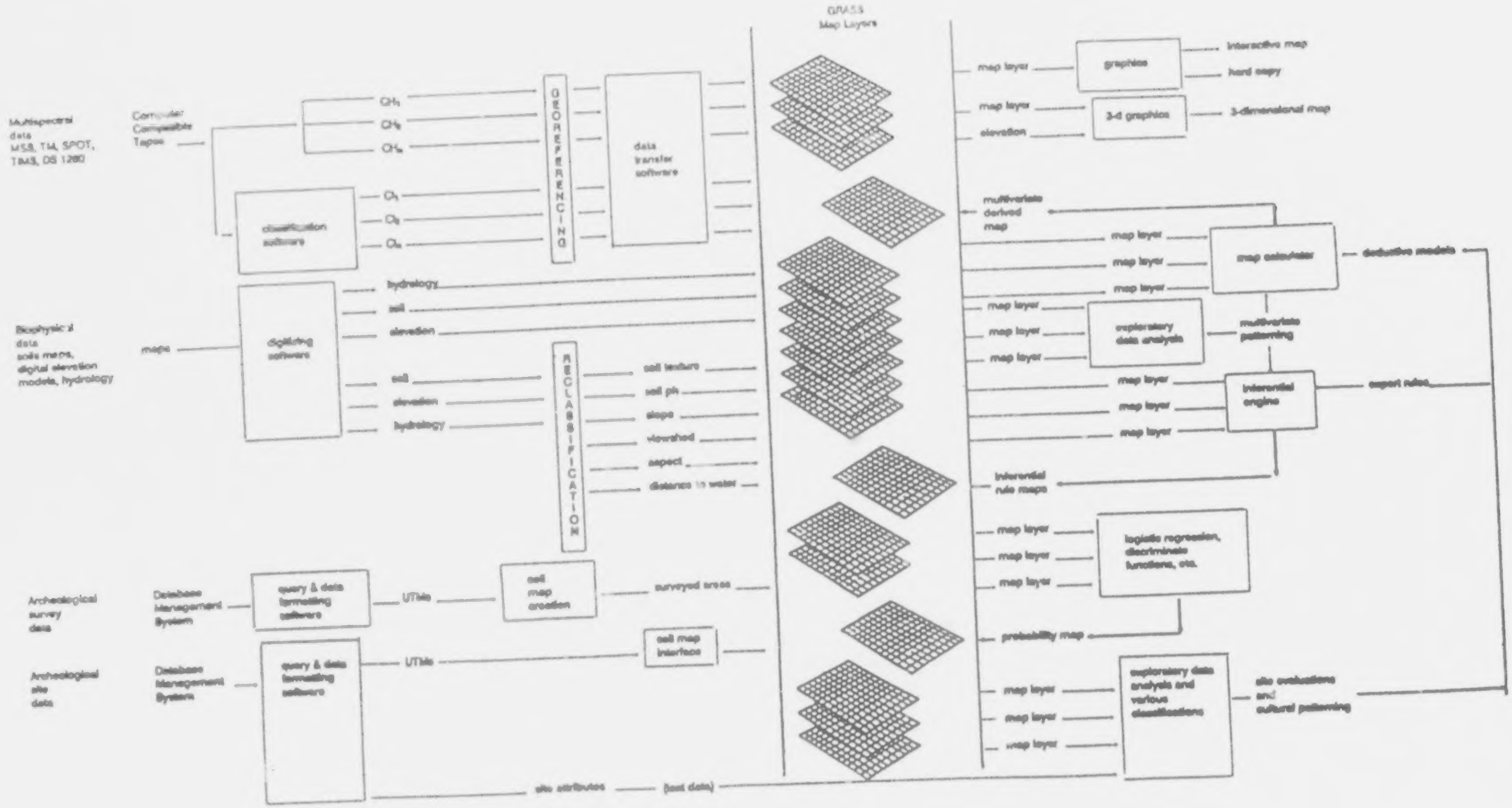
proposals for GIS applications generally are widespread (cf. esp. Kvamme 1985, Lafferty et al. 1981). Among the earliest successful applications of many of these proposals was the work of Craig et al. (1978). In this study Landsat-MSS data was merged with a variety of other data layers in an investigation of land use in the Denver area. It is essential, however that the various components of the system be "integrated". Rather than independent hardware/software/dataset's the entire system structure should be considered and elements designed in a "top-down" fashion (Martin 1983). Until relatively recently such integration was difficult to perform because of a variety of hardware and/or software limitations. Today, however, these limitations have been removed. Work conducted by the Construction Engineering Research Laboratory, the Space Remote Sensing Center, University of Washington Statistical Laboratory, the MASSCOMP Corporation, and the Arkansas Archeological Survey now make an easy to use integrated system widely available at relatively low cost.

The overall structure of one such currently operating system is illustrated in Figure 4. The system includes comprehensive relational databases utilizing the INFORMIX DBMS for archeological sites, projects, citations, artifacts and ancillary data. Other major softwaqre components include remote sensing software (ELAS), a comprehensive GIS (GRASS) and Bell Laboratory's powerful EDA software "S". All software resides on a MASSCOMP 5600 high performance graphics workstation. All database elements and GIS components have been designed to allow easy export/import. Arkansas Archeological Survey staff have written specific software to (1) transfer ELAS data to GRASS, (2) present menu front end for S to process GRASS derived data (3) query the relational database and reformat output suitable as input to GRASS and S. GRASS and ELAS are public domain, as are the interfaces. INFORMIX and S are available commercially at a nominal cost. Contact the Space Remote Sensing Center, NSTL, MS for information.

We have noted the role played by the GRASS GIS earlier in this paper. In another paper Farley (1987) has discussed the elements of the structure, excepting the remote sensed components. In particular, he presents information on the application of EDA methods and their predictive role.

Earlier archeological researchers have successfully utilized remote sensed imagery in a GIS context, e.g. Wells et al. (1981), Custer et al. (1983, 1984, 1986) and Holmer (1986). As is the case with the sensor IFOV, cell resolution in the GIS is important. Wells et al. (1981) utilized a cell size of 400 m x 400 m and the Landsat MSS sensor. Holmer also used the Landsat MSS and used a cell size of 500 m x 500 m. The SPOT data discussed by Limp (1987b) was utilized in a 20 m cell size GIS and the DS1260 data utilized a 10 m cell for the GIS applications. Clearly, these smaller cell sizes have numerous advantages, however, data acquisition costs/time and processing can be limiting, as can increased "noise". Effective digitizing options, as well as use of digital data sources whenever available, are essential. The hardware environment must also be capable of dealing with the large data files and high resolution display needs.

FIGURE 4. INTEGRATED STRUCTURE INCORPORATING REMOTE SENSING, GEOGRAPHIC INFORMATION SYSTEMS, DATABASE MANAGEMENT SOFTWARE AND EXPLORATORY DATA ANALYSIS FOR THE STUDY OF ARCHEOLOGICAL SITES


Multispectral data MSS, TM, SPOT, TMS, DS 1260
Computer Compatible Tapes
Ch_1
Ch_2
Ch_n
classification software
C_1
C_2
C_n
GEOREFERENCING
data transfer software
Biophysical data soils maps, digital elevation models, hydrology
maps
digitizing software
hydrology
soil
elevation
soil
elevation
hydrology
RECLASSIFICATION
soil texture
soil ph
slope
viewshed
aspect
distance to water
Archeological survey data
Database Management System
query & data formatting software
UTlife
cell map creation
surveyed areas
Archeological site data
Database Management System
query & data formatting software
UTlife
cell map interface
site attributes
(test data)
GRASS Map Layers
map layer
graphics
interactive map
hard copy
map layer
elevation
3-d graphics
3-dimensional map
multivariate derived map
map layer
map layer
map layer
map calculator
deductive models
map layer
map layer
map layer
exploratory data analysis
multivariate patterning
map layer
map layer
map layer
inferential engine
expert rules
inferential rule maps
map layer
map layer
map layer
logistic regression, discriminate functions, etc.
probability map
map layer
map layer
map layer
exploratory data analysis and various classifications
site evaluations and cultural patterning

Work is continuing on GIS data acquisition for the Lee Creek, Frog Bayou and Green Tree study areas. When the data layers are completed, a variety of robust pattern recognition techniques will be utilized. In particular, a suite of logistic and robust binary regression techniques now available in S (Douglas Martin, personal communication) will be applied.

SUMMARY

Data from sensors with high spectral resolution and small IFOVs can be utilized for the successful classification of archeological sites. Parameters are site size, intensity of occupation, and perhaps most important, the relative degree of environmental circumscription and the relationship between site proxy properties and the "background". Use of an integrated system involving remote sensing, geographic information systems, database management and exploratory data analysis increases significantly the usefulness of the remote sensed data.

ACKNOWLEDGMENTS

Support for the research discussed here was made available by the U.S. Army Corps of Engineers' Southwestern Division and Construction Engineering Research Laboratory, the Space Remote Sensing Center, and the Massachusetts Computer Corporation. Their assistance is gratefully acknowledged. Individuals assisting the study were Larry Banks, Gary Earls, Manuel Barnes, Scott Madry, David Wagner, Carl Schueler, Lance McKee and James Farley.

REFERENCES

ADAMS, R. F. W.; BROWN, W.; CULBERT, P., "Radar Mapping, Archaeology and Ancient Land Use in the Mayan Lowlands," JPL Report N82-11514, 1981a.

ADAMS, R. F. W.; BROWN, W.; CULBERT, P., "Radar Mapping, Archaeology and Ancient Maya Land Use, Science, 1981b, No. 213.

ANDERSON, J. E., "Mid/thermal IR Remote Sensing," NASA/ERL Report 214, 1983.

BAKER, C.; SESSIONS, S., "Predictive Model Development and Evaluation," in Archeological Variability Within the Bisti-Star Lake Region, edited by Kemrer, M. F., ESCA-Tech Corp., Albuqueque, 1982, pp. 121-173.

BARISANO, E., "Methodological Research in Connection with the Handling of Landsat Satellite Data for Archaeology," EARSeL/ESA Symposium on Integrative Approches in Remote Sensing, 1984, pp. 47-49.

BARISANO, E.; HELLY, B., "Remote Sensing and Archaeological Research in Thessaly (Greece); New Prospects in 'Archeological' Landscape," EARSeL/ESA Symposium on European Remote Sensing Opportunities, 1985, pp. 203-209.

BOTKIN, D.; ESTES, J.; MACDONALD, R.; WILSON, M., "Studying the Earth's Vegetation from Space," Bioscience, Volume 34, No. 8, 1984, pp. 508-514.

BERTA, S; HARRINGTON, J., "Quartermaster Creek Watershed Land Cover Types," in Archaeology of the Mixed Grass Prairie, edited by Baugh, T., Oklahoma Archeological Survey Report No. 20, 1984.

BROWN, G.; EBERT, J., "Ecological Mapping for Purposes of Sample Stratification in Large-Scale Cultural Resources Assessment: The National Petrolium Reserve in Alaska," in Remote Sensing and Nondestructive Archeology, edited by Lyons, T. R. and Ebert, J., National Park Service, Washington D.C., 1978, pp. 53-63.

CAMILLI, E., "Remote Sensing and Cultural Resources Management for the Navajo Indian Irrigation Project (NIIP)," in Report of the Cultural Resources Survey of Blocks VI and VII of the NIIP, by Reynolds, W., Camilli, E., and Mayfield, D., ESCA-Tech Corporation, Albuquerque, 1979a.

CAMILLI, E., "The Sampling Design and Known Cultural Resource Locations," in Preliminary Report: Reconnaissance Survey of the Archaeological and Related Resources of the Lower Puerco and Salado Drainages, Central New Mexico, edited by Wimberly, M. and Eidenbach, P., Human Systems Research, Tularosa, New Mexico, 1979b, pp. 24-34.

CAMILLI, E., "An Ecological Cover-Type Map of the San Juan Basin, Northwestern New Mexico," in Remote Sensing in Cultural Resource Management: The San Juan Basin Project, edited by Drager, D. L. and Lyons, T.R., Cultural Resource Management Divisions, National Park Service, Washington D.C., 1984, pp. 39-56.

CAMILLI, E.; SEAMAN, T., "Preliminary Assessment of Cultural Resources for the Crownpoint to Bisti Water Pipeline Route: Cultural Resources Management with the Aid of Remote Sensing," in New Mexico Generating Station Environmental Assessment, Public Service Company of New Mexico, Albuquerque, 1979.

CRAIG, T.; MILLER, L.; CHRISTENSON, J., "Spatial Land-Use Inventory, Modeling and Projection/Denver Metroolitan Area," NASA Technical Memo 79710, 1978.

CRIST, E.; CICONE, R., "Application of the Tasseled Cap Concept to Simulated Thematic Mapper Data," Photogrammetric Engineering and Remote Sensing, No. 50, 1984, pp. 343-352.

CUSTER, J.; EVELEIGH, T.; KLEMAS, V., "A LANDSAT-Generated Predictive Model for Prehistoric Archaeological Sites in Delaware's Coastal Plain," Bulletin of Archeological Society of Delaware, No. 14, new series, 1983, pp. 19-38.

CUSTER, J.; JEHLE, P.; KLATKA, T.; EVELEIGH, T., A Cultural Resources Reconnaissance Planning Study of the Proposed Route 13 Relief Corridor, New Castle and Kent Counties, Delaware, Location and Environmental Studies Office, Division of Highways, Delaware Department of Transportation, Dover, 1984.

CUSTER, J.; EVELEIGH, T.; KLEMAS, V.; WELLS, I, "Application of Landsat Data and Synoptic Remote Sensing to Predictive Models for Prehistoric Archaeological Sites: An Example from the Delaware Coastal Plain," American Antiquity, volume 51, 1986, pp. 572-588.

DRAGER, D., "Projecting Archeological Site Concentrations from Cover-Type Maps Developed from Remote Sensing Data," Proceedings of the Second Conference on Scientific Research in the National Parks Held at San Francisco, California, on November 26-30, 1979, Volume 1, 1980a, pp. 151-157.

DRAGER, D., "Vegetative Stratifications from Aerial Imagery," in Cultural Resources Remote Sensing, edited by Lyons, T. R. and Mathien, F. J., National Park Service, Washington D.C., 1980b, pp. 79-86.

DRAGER, D.; LYONS, T., editors, Remote Sensing in Cultural Resource Management: The San Juan Basin Project, Cultural Resources Management Division, National Park Service, Washington D.C., 1984.

DRAGER, D.; EBERT, J.; LYONS, T., "Remote Sensing and Nondestructive Archeology: Approaches to Cultural Resource Management," in The San Juan Basin Tomorrow: Planning for the Conservation of Cultural Resources in the San Juan Basin, edited by Plog, F. and Wait, W., National Park Service, Southwest region, Albuquerque, 1982, pp. 219-244.

EBERT, J., "Remote Sensing and Large-Scale Cultural Resources Management," in Remote Sensing and Nondestructive Archeology, edited by Lyons, T. R. and Ebert, J. I., National Park Service, Washington D.C., 1978, pp. 21-34.

EBERT, J.; LYONS, T., "Remote Sensing in Archaeology, Cultural Resurces Treatment and Anthropology," Aerial Archaeology, volume 5, 1980, pp. 1-19.

EL BAZ, F., "Geographic and Geologic Setting of the Tomb of Nefertari, Egypt," Center for Remote Sensing Technical Paper No. 1, Boston University, 1986.

EL SHAZLY, E., "Space Borne Imagery Interpretation of Mega Features Related to Egyptian Archeology," IGARSS '83, 1983, pp. 1.4.1-4.6.

ELSTON, R.; WHITLEY, D.; BERRY, M.; LICHTY, A.; DREWS, M.; ZEIER,C., Class II Archaeological Survey of Selected Portions of the Naval Weapons Center, China Lake, California, Intermoutain Research, Silver City, Nevada, 1983.

FARLEY, J., "The Land Managers Dilemma: Monitoring Multidimensional Resource Associations in a Three Dimensional World,"

FARLEY, J.; POWELL, B.; LIMP, W., "GRELAS Users Guide," Arkansas Archeological Survey Technical Note, 1987.

FINDLOW, F.; CONFELD, L., "Landsat Imagery and the Analysis of Archeological Catchment Territories: A Test of the Method in Catchment Analysis," Essays on Prehistoric Resource Space, edited by Findlow, F. and Erickson, J., Anthropology, volume 10, number 1-2, 1980, pp. 31-52.

FORSHAW, M.; HASHELL, A.; MILLER, P.; STANLEY, D.; TOWNSHEND, J., "Spatial Resolution of Remotely Sensed Imagery, a Review Paper," International Journal of Remote Sensing, volume 4, 1983, pp. 497-520.

GAUSMAN, H.; ESCOBAR, D.; EVERITT, J.; RICHARDSON, A.; RODRIGUIZ, R., "Distinguishing Succulent Plants from Crop and Woody Plants," Photogrammetric Engineering and Remote Sensing, volume 44, 1978, pp. 487-491.

GILLESPIE, A.; KAHLE, A.; PALLUCONI, F., "Mapping Alluvial Fans in Death Valley Ca Using Multichannel Thermal Infrared Images," Geophysical Research Letters, volume 11, 1984, pp. 1153-1156.

GORAN, B., WESTERFIELD, J.; SHAPIRO, M.; JOHNSON, M., "GRASS Users Manual, Version 2," U.S. Army CERL, 1987.

GRAHAM, M.; JUNKIN, B.; KALCIC, M.; PEARSON, R.; SEYFARTH, B., "ELAS Users Guide," NASA/ERL, 1987.

GUMERMAN, G.; LYONS, T., "Archeological Methodology and Remote Sensing," Science, volume 172, 1971, pp. 126-132.

HILLIARD, J.; RIGGS, J., "AMASDA Site Encoding Manual," Arkansas Archeological Survey Technical Paper No. 1, 1986.

HOLMER, R., "Castle Valley Rail Line Denver and Rio Grande Western Railroad Known Archeological and Historical Site Evaluation and Predictive Model," University of Utah Archeological Center Reports of Investigations, No 82-01, 1982.

INGLIS, M.; BUDGE, T.; EBERT, J., "Preliminary Evaluation of Simulated SPOT Data for Cultural Resource Assessment Management, New Mexico," SPOT Simulation Applications Handbook, 1984, pp. 73-82.

JENSEN, J. R., Introductory Digital Image Processing, Prentice Hall, 1986.

KAUTH, R.; THOMAS, G., "The Tassled Cap," Proceedings, Symposium on Machine Processing of Remotely Sensed Data, West Lafayette, Indiana, 1976, pp. 41-51.

KVAMME, K., "Determining Empirical Relationships Between the Natural Environment and Prehistoric Site Locations," in For Concordance in Archaeolcgical Analysis, edited by Carr, C., 1985, pp. 208-238.

LADE, K., "The Monitoring and Detection of Archaeological Reosurces in Maryland Through Use of Landsat Digitized Multispectral Data," Paper presented at 44th Annual Meeting of the SAA, Minneapolis, 1982.

LAFFERTY, R.; OTINGER, J.; SCHOLTZ, S.; LIMP, W.; WATKINS, B.; JONES, R., "Settlement Prediction in Sparta," Arkansas Archeological Survey Research Series 14, 1981.

LIMP, W., "Remote Sensing for Cultural Resource Management, An Overview," Report Submitted to U.S. Army Corps of Engineers, Southwestern Division, 1987a.

LIMP, W., "Preliminary Report on the Results of Comparison of the effectiveness of SPOT and Thematic Mapper Sensors for Archeological Site Discovery," Report Submitted to Space Remote Sensing Center, NSTL.

LIMP, W.; PARKER, S.; FARLEY, J.; WADDELL, D.; JOHNSON, I., "An Automated Data Processing Approach for Natural Resurces Management on Military Installations," Arkansas Archeological Survey, submitted to U.S. Army CERL, 1987.

LYONS, T.; EBERT, J., editors, "Remote Sensing and Nondestructive Archeology," Cultural Resources management Division, National Park Service, Washington D.C., 1978.

MADRY, S., "A Multiscalar Application of Remote Sensing in a Temperate Regional Archaeological Survey," Technical Paper of the 50th Annual Meeting of the American Society of Photogrammetry, 1984.

MCANANY, P. A.; NELSON, B. A., Cultural Resources Overview for the New Mexico Synfuels, 1982.

MARTIN, J., "Managing the Database Environment," Prentice Hall, 19

MID-AMERICA REMOTE SENSING CENTER, "Determination of the Utility of Remote Sensing for Land Use/Cover Analysis in the Lower Appalachia Region," Final Report NAS13-200, NASA-ERL NSTL Ms, 1983.

MILLER, F., "Remote Sensing Techniques in Historical Site Discrimination," Remote Sensing of Environment, volume 11, 1986, pp. 463-471.

MORAIN, S.; BUDGE, T.; KOMAREK, A., "An Airborne Spectral Analysis of Settlement Sites in Chaco Canyon," in Remote Sensing: Multispectral Analysis of Cultural Resources, National Park Service, Washington D.C., 1981.

MORAIN, S.; NELSON, C.; WHITE, M.; KOMAREK, A., "Remote Detection of Prehistoric Sites in Bandelier National Monument," in Remote Sensing: Multispectral Analysis of Cultural Resources, National Park Service, Washington D.C., 1981.

NASA, "Land-Related Global Habitability Science Issues," NASA Technical Memo 85841, 1983.

PALLUCINO, F.; MEEKS, G., "Thermal Infrared Multispectral Scanner (TIMS): An Investigator's Guide to TIMS Data, JPL Publication 85-32, 1985.

PARKER, S.; LIMP, W.; FARLEY, J.; JOHNSON, I., "Integrated Approach to Database Management and Geographic Inormation Systems for the U.S. Forest Service," Arkansas Archeological Survey, submitted to U.S. Forest Service, Region 8, 1986.

TABBAGH, A., "Evaluation of the Use of Thermal Airborne Prospection for Archaeology during the Last Ten Years," Proceedings of IGRASS 84, volume 1, 1984, pp. 205-208.

SEVER, T., "Feasibility Study to Determine the Utility of Advanced Remote Sensing Technology in Archaeological Investigations," ERL-NSTL Report No. 227, 1983, pp. 1-30.

WANDSNIDER, L.; EBERT, J., "Modeling Climatic and Land Form Factors Affecting the Character of the Archeological Record in Arid Lands," in The Seedskadee Project, edited by Drager, D., and Ireland, A., National Park Service, Southwestern Region, 1986, pp. 23-48.

WELCH, R., "Spatial Resolution Requirements for Urban Studies," International Journal of Remote Sensing, volume 3, 1982, pp. 139-146.

WELLS, I.; CUSTER, J.; KLENAS, V., "Locating Prehistoric Archaeological Sites Using Landsat," Proceedings of the 15th International Symposium in Remote Sensing of Environment, Ann Arbor, 1981, pp. 771-779.

REMOTE SENSING AND GIS: PREDICTING SEDIMENT LOADING AND NUTRIENT EXPORT FOR WATERSHED MANAGEMENT

Samuel F. Atkinson , Ph.D.

Director, Center for Remote Sensing
and Landuse Analyses, North Texas State University, Denton, TX

ABSTRACT

An attempt to analyze the watersheds of four drinking water reservoirs is described. The watersheds occupy 1.6 million acres in North Central Texas. The objective of the study was to identify "critical zones", defined as those areas most likely to contribute to water quality degradation through nonpoint pollution.

The approach involved LANDSAT MSS acquired in 1974, 1977, 1981 and 1986. Landuses in the watersheds were determined using maximum likelihood techniques for each year and placed into a geographic information system (GIS). Other variables which are known to influence the quality of water flowing over the land surface (e.g., soil type, slope, length of slope, and rainfall occurrence) were also entered into the GIS. Nutrient export coefficients were linked to the GIS variables in the watersheds and predictions of average reservoir water quality were made. Quantitative analyses of landuse change over the 14 year record of MSS data pointed to areas moving from noncritical into critical status.

These predictions will ultimately help decision makers responsible for the drinking water in the reservoirs. The predictions will guide the selection of water treatment options, whether the options involve nonpoint pollution control or treatment of water at the point of withdrawal.

INTEGRATING GIS AND REMOTE SENSING DATA

D.G. Goodenough

and

K.B. Fung

Canada Centre for Remote Sensing
2464 Sheffield Road
Ottawa, Ontario, Canada

and

W.J. Craig

Intera Technologies, Inc.
1525 Carling Avenue, Ottawa
Ontario, Canada

ABSTRACT

The Canada Centre for Remote Sensing (CCRS) has been working with the Inventory Branch of the British Columbia Ministry of Forests and Lands (BCMFL) to integrate a geographical information system (GIS) with remotely sensed data. The objective of this work is to update forestry inventory maps effectively using remote sensing techniques. Initial studies have shown that remotely sensed data can be used to update the forest cover maps. Studies by Goodenough (1987) have shown that clearcut boundaries can be mapped successfully using remotely sensed data and integrated into the forest GIS.

An area north of Cranbrook, British Columbia has been selected as the test site for our research. The selected area has a topographic variation of about 1000 meters. The input data to this project include the corresponding digital elevation models. The TM images are geometrically rectified to federal UTM maps at 1:50,000 scale with ground control points. The inventory maps are UTM at 1:20,000 scale and are produced using the British Columbia provincial base maps. This paper will report and discuss the results of the following studies.

Development of a Geographic Information System for the Saylorville River Basin, Iowa

Carolyn J. Merry[1], Thomas Eagle[2],
Nancy LaPotin[1] and Janice Gardiner[3]

[1]U.S. Army Cold Regions Research and Engineering Laboratory
72 Lyme Road, Hanover, New Hampshire 03755-1290

[2]Department of Geography, [3]Department of Earth Sciences
Dartmouth College
Hanover, New Hampshire 03755

ABSTRACT

CRREL's image processing and Geographic Information System (GIS) efforts with the Rock Island District have concentrated in Iowa on the Kanawha and Clarion watersheds in the Saylorville River Basin. The Landsat Thematic Mapper (TM) 30-m data and Système Probatoire d'Observation de la Terre (SPOT) High Resolution Visible (HRV) 20-m multispectral data were classified into seven land cover classes. Ground truth data were collected after the satellite overflights and are being used to determine the accuracy of the classification scheme. These land use maps will be placed into a GIS containing soils and elevation data at a 30-m grid cell size and basin boundary data. A procedure is being developed to link the GIS and the Corps Hydrologic Engineering Center Data Storage System (DSS) to provide the data base to use with Corps real-time hydrologic forecasting models.

INTRODUCTION

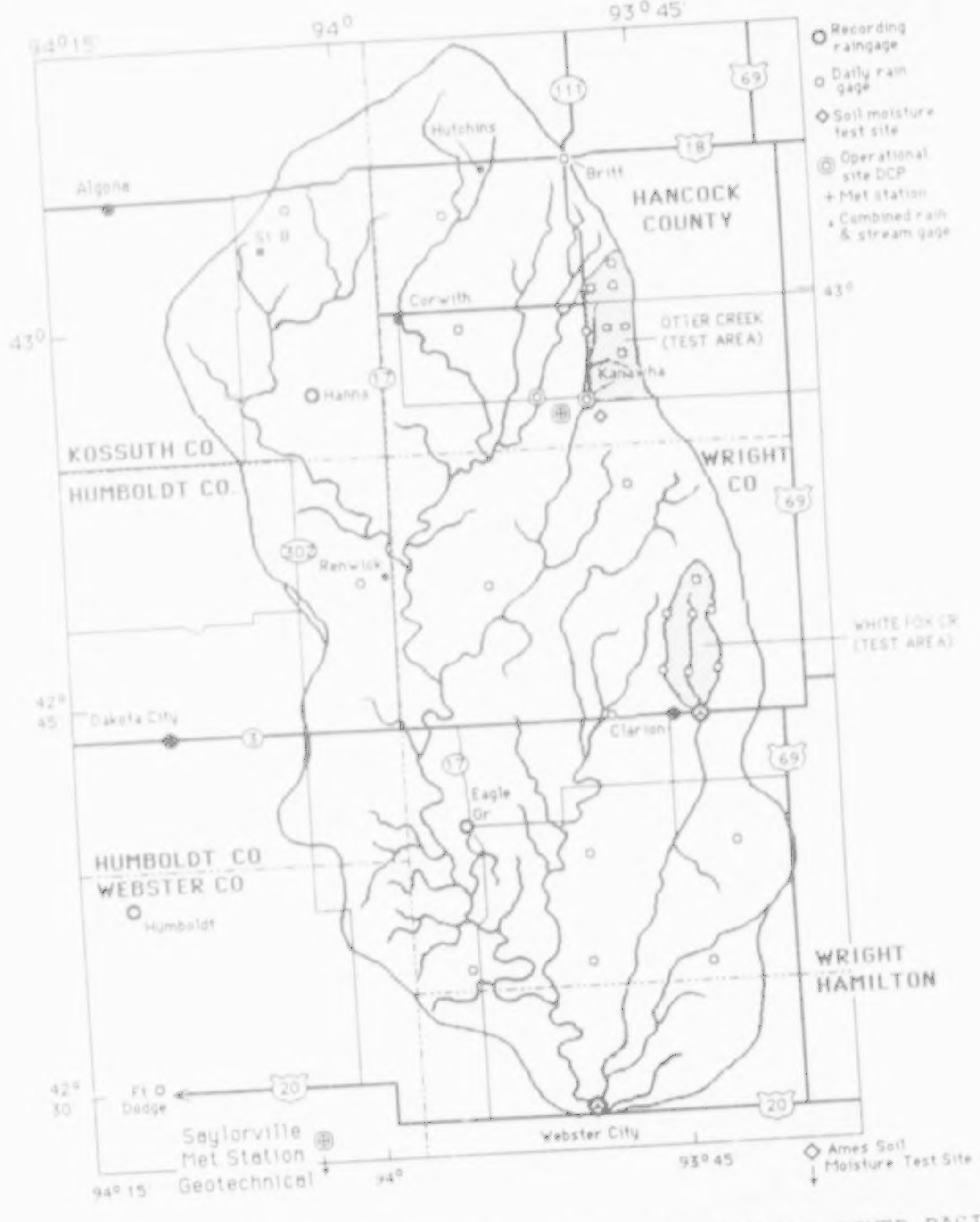
The Inland Water Resources Remote Sensing Demonstration Program will run for five years. It is a cooperative project between CRREL and the Rock Island District. One objective of the program is to demonstrate the use of in situ, aircraft and satellite remote sensing data in the Corps' water resource mission area. Comparisons of information content, reliability, the cost of acquiring and analyzing remote sensing data, and integrating the remotely sensed data into the Corps Water Control Data System (WCDS) are being addressed in the study.

Specific remote sensing technology applications are being demonstrated for several Rock Island District functions. These include evaluating sensors that acquire real-time data about environmental, hydrologic and geotechnical parameters for determining dam and levee structure integrity; collecting water control data for navigation, reservoir regulation, basin hydrologic monitoring and model validation; monitoring water quality for dredging, hydropower and reservoir regulation; and developing a spatial data base for use in real-time flood forecasting models.

SPATIAL DATA DEVELOPMENT

In the Corps Civil Works community, spatially oriented data are used in many planning studies. These spatial data are analyzed in a Geographic Information System (GIS). The data in a GIS are usually at the highest resolution required for a particular study. The size of the grid cell depends on the way the data will be ultimately used.

One of the more powerful uses of the satellite imagery is incorporating the digital data into GISs that can be accessed by a number of hydrologic, economic and environmental models. The advantage of using remote sensing information is that the data come in a digital format and are spatially oriented, and, therefore, can be easily incorporated into the GIS.



94° 15'
94°
93° 45'
Recording raingage
Daily rain gage
Soil moisture test site
Operational site DCP
+ Met station
Combined rain & stream gage
69
111
18
Hutchins
Britt
Algona
HANCOCK COUNTY
St B
Corwith
43°
OTTER CREEK (TEST AREA)
Kanawha
17
Hanna
KOSSUTH CO
HUMBOLDT CO
WRIGHT CO
302
Renwick
WHITE FOX CR (TEST AREA)
42° 45'
Dakota City
3
Clarion
Eagle Gr
HUMBOLDT CO
WEBSTER CO
Humboldt
WRIGHT
HAMILTON
42° 30'
Ft Dodge
20
Saylorville Met Station Geotechnical
Webster City
Ames Soil Moisture Test Site

FIGURE 1 - SITE LOCATION MAP OF THE UPPER SAYLORVILLE RIVER BASIN.

A spatial data base is being developed for two watersheds in the Upper Saylorville River Basin. We are beginning our analysis in an 844-square-mile watershed of the Saylorville River Basin (Fig. 1). Two small scale watersheds, the West Otter Creek, near Kanawha (14.9 sq miles), and the White Fox Creek, near Clarion (13.3 sq miles), are being studied intensively. They will serve as training sites for extending the results to the entire Des Moines River Basin.

Soil, elevation and land cover data sets are being configured CRREL's Dipix ARIES-II image processing system. The soil maps are digitized by Iowa State University at a 30-m grid cell size. When the maps are digitized, the data set will be merged into the GIS.

The DEM (Digital Elevation Model) data tape for the study site has been acquired from the Defense Mapping Agency. The elevation data were digitized at a 30-m resolution. A procedure is being developed to merge the elevation data set into the GIS.

Data sets of land cover were prepared from a Landsat TM image acquired on 3 September 1982 and a SPOT HRV scene acquired on 17 July 1987. Various aggregation schemes have been developed to allow grouping of the 20- and 30-m pixels into larger grid cell sizes. The aggregated data sets can be tested through use of the HEC-1F (Hydrologic Engineering Center, Flood Hydrograph Package, forecasting portion) model.

The Landsat TM data were mapped into seven classes using a supervised maximum likelihood classifier that is part of the ARIES-II software. These seven classes are town, corn, wet areas (marsh), soybeans, bare ground, water and oats (hay). A similar land cover classification was created on the SPOT HRV image; however, we used a two-level classification technique because of the similarities in corn and soybean reflectance characteristics in July. We separated the corn and soybean classes in the first level; in the second level we separated out the remainder of the classes and then merged the two classifications.

The ground truth for verifying the land cover map was collected during the summer of 1986 for the 1982 TM image and during the summer of 1987 for the 1987 SPOT image. Field data maps and statistics associated with crop types and acreages were obtained from the Soil Conservation Service (SCS). The accuracy of mapping the land cover units to an 85% level is being determined.

SOFTWARE DEVELOPMENT FOR DSS

The HEC Data Storage System (DSS), shown in the box called "DSS" and "DSS Software" in Figure 2, is a hydrologic information and analysis computer system designed to handle water resources data of various types. These data are collected over time and stored in DSS as site-specific data. For example, data on streamflow at a particular gauging station are collected over time and stored in the system as a data file in which the name indicates the project or basin name, the location (gauging station name), the data types (streamflow), and the frequency of data collection (daily, weekly or monthly). DSS has utility, analysis and display software that enable a user to easily access, display, edit and use the data as input to various HEC hydrologic models.

The satellite remote sensing data to be incorporated into DSS are fundamentally different from the water resources, site-specific (point) data that are currently in DSS: they are not data that are collected at

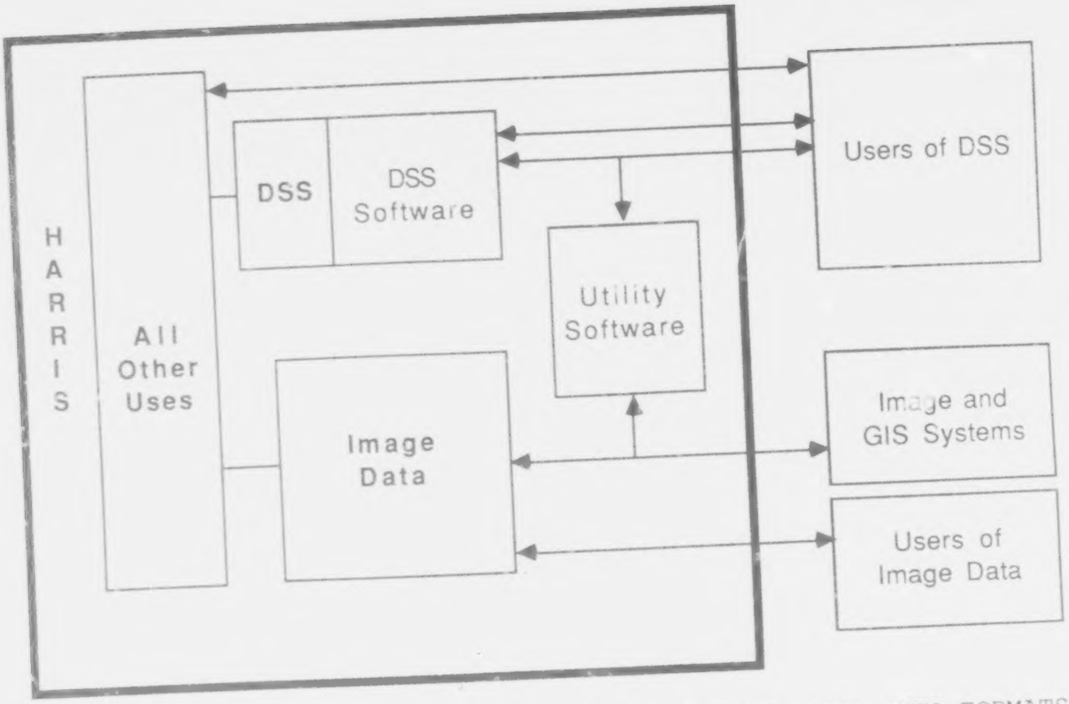


FIGURE 2 - PROPOSED SYSTEM FOR TRANSFORMING IMAGE DATA INTO FORMATS USEFUL FOR REAL-TIME HYDROLOGIC FORECASTING MODELS WITHIN DSS.

or for a single point. The satellite data are collected over a large area with the resolution depending on the sensor. The data are stored in a grid cell format (raster) and one set of data may overlap or completely align with another data set. The typical size of a data set for a satellite scene is extremely large and cannot be analyzed or displayed with the current DSS software.

Given the amount of information we currently have on the HEC models, it is unlikely that the forecasting models will use all of the satellite remote sensing data in the typical grid cell format. It is more likely that these data must be aggregated or summarized to a stream basin or subbasin measure. This measure would then be used as input to the HEC models. Whether the measure is a real-time input variable or a known parameter that is fixed over a period of time depends on the model being used. Some forms of satellite data are not collected routinely over time nor with a frequency for which the HEC models and analysis programs, including the utility software, are designed to handle.

It is, however, extremely important to have the processed satellite data centralized on the same main frame computer as DSS. This enables the Corps District office to have access to the image data and DSS at the same time, if needed. Centralizing the software storage on the Corps' Harris main frame computer also provides control over the data incorporated into the overall system, allowing us to control the amount of data, the quality of data, the resolution of the data, and the land coverage of the data. Strict controls over access, particularly in terms of adding new image data files, would be used. Decisions of online vs. offline storage could be easily made by using the centralized location design.

READEX best copy available

For these reasons, we propose testing an additional data base, shown as the box "Image Data" in Figure 2, on the Harris main frame computer that will contain the satellite remote sensing data. This data base will not be directly incorporated into DSS, but rather it will reside as an image data file server, providing access to users for analysis, downloading or displaying images.

The connection to DSS will be twofold. First, the data set naming convention used in DSS will be used. The names will provide a user with information on the project name or coverage area (location of basin area) or both, basin name, data type (land cover, soil type, land use, snow cover, etc.), the date when the data were collected, the resolution of the data, and other important ancillary information. The exact convention used is being worked out with HEC to ensure a systematic coordination of the file names. The data will be stored on the Harris computer in a standard binary image data file format that would be generic enough to allow users to download the image scene to a variety of image processing computer systems.

Second, a set of utility and analysis software packages, shown as the box called "Utility Software" in Figure 2, would be created and used to transform the grid cell data into the point, subbasin, basin or summarized form necessary for use in the HEC models. Such software would be developed and used as needed. The software could be used when a new image is placed into the image data base. It is also possible that the software could be run often and the results of the operations stored in summary form as a data file directly within DSS. This software would be added to software currently available in the DSS system.

SUMMARY

A GIS is being developed for two watersheds in the Upper Saylorville River Basin. Software is being developed to integrate an image data file structure into DSS and to use summarized forms of the image data for use with the HEC models. Once completed, the GIS will be tested with the HEC-1F model for the Kanawha and Clarion watersheds. Once the model has been calibrated and tested on the two watersheds, we will extend the analysis to the entire Saylorville River Basin.

ACKNOWLEDGEMENTS

The study is funded by the Inland Water Resources Remote Sensing Demonstration Program (under Inter-Army Reimbursable order no. USAED, RI #NCR-IA-87-0026) by the Construction and Operations Readiness Division, Office of the Chief of Engineers. The authors wish to extend their appreciation to Dr. Harlan L. McKim (CRREL) who is the Program Manager for the Demonstration Program, and to Timothy Pangburn and Richard Haugen (CRREL) and Dr. McKim for their technical review of this paper.

SESSION VI

CRREL's EXPERIENCES OF REMOTE SENSING TECHNOLOGY TRANSFER TO THE CORPS USER

Carolyn J. Merry
U.S. Army Cold Regions Research and Engineering Laboratory
72 Lyme Road, Hanover, New Hampshire 03755-1290

ABSTRACT

The technology transfer mechanisms that have worked successfully at CRREL include: working one-on-one with District people, a Remote Sensing Bulletin, telephone consultation, training courses, and moving toward a PC environment. The paper describes in detail these five areas.

REMOTE SENSING TECHNOLGY TRANSFER

We have found at CRREL that our most successful technology transfer mechanisms have occurred in five main areas. They are:

- working one-on-one with District people,
- a Remote Sensing Bulletin,
- telephone consultation,
- training courses, and
- moving toward a PC environment.

The following paragraphs describe in more detail these five areas.

The first avenue that we find works very well for technology transfer is when individuals come to CRREL and stay for an extended period of time. We have had people in for as little as a day, for a week, and for as long as three months. The longer the individual stays and the more that they work on computer equipment, the better they understand the use of the remote sensing data for their own work. We have also found that if the remote sensing data are for a project that they are conducting in their own District, then they are much more interested and eager to work with the data.

We have also found that going to a District office and working directly with the individuals on their own image processing or comparable system is also an effective way to quickly transfer the remote sensing data quickly. For example, we have worked with District individuals to get software running on their Harris. This is not an easy task, and one must be at the terminal making sure everything runs. We have also worked with the District people on their own image processing system to answer questions for a particular task. Normally a task using an image processing system asks various questions of the operator. If you do not understand the question, then you are not sure if the objective of the work is being properly addressed. That can be quite frustrating.

Second, we publish a Remote Sensing Information Exchange Bulletin. The fourth Bulletin was printed in time to be at the Sixth Remote Sensing Symposium. Our distribution list is over 1000 names. This Bulletin grew out of one of our remote sensing meetings held at the North Central Division. One of our remote sensing coordinators had suggested that we start a newsletter that would be distributed throughout the Corps. As a result of his suggestion, our first one was published in November 1983.

Articles for the Bulletin are solicited from the Districts and Divisions, and the response has been good. However, it does involve some arm-twisting and numerous phone calls to get the articles in from the

Districts. Once the Bulletin is published, everyone enjoys the publication and the enthusiasm remains high for quite some time. However, getting the articles to CRREL in a timely manner is not easy.

The third area is the telephone. We get numerous phone calls asking questions such as: how do we get remote sensing data, what will this type of data give me in terms of resolution and spectral information, can you help us with a particular project, or can you program a satellite to get us an image. A lot of the questions can be answered quickly on the telephone, our one-stop service, but many require a little bit more "digging" to get the answer to them.

The fourth way is in training courses. Many of the universities offer very good training courses for the inexperienced user. These range from a full-blown course to a short course. The companies that sell image analysis systems will also train the purchasers of their system. Some of these companies will give a "quick and dirty" introduction to the fundamentals of remote sensing. However, we do find that they only skim the surface. A more in-depth course is best available from a university environment.

We used to have a remote sensing course available for digital image processing, but somehow it got lost or the field lost interest. We still have a remote sensing class taught by Bob Frost (ETL), but this stresses photointerpretation and photogrammetry. And at one time, we had a remote sensing class for the manager. This was quite successful and did a good job to educate our Corps section, branch and division chiefs on what could be obtained from remote sensing data. However, somehow the interest for this course also waned. We will institute training or workshop sessions when the Remote Sensing Assistance Center at USACRREL gets started, but presently the best way to get training is by attending a university-sponsored course.

The Detroit District sponsored an in-house training program consisting of about 80 hours of instruction. The instructors were from the Environmental Research Institute of Michigan, nearby universities and other institutions. This program was quite successful and trained many people in the Detroit District. This type of training involves a District course coordinator and requires a sizeable commitment of time.

The fifth way for technology transfer is by transferring the software to the PC environment. We know the Harris is expensive and sometimes the response time is slow if there are a lot of users on the system. The operating system for a computer such as the Harris can be quite intimidating. A lot of people are not afraid of working with a small computer that is located on their desk. I would rather crash my own PC than to crash a big computer system. Also, the operating environment for a PC is a lot easier to understand than a big computer system. As a result, the potential for Corps users to use remote sensing is greater if the software is developed to run on a PC. For example, we have taken steps to do heavy number crunching on our Dipix ARIES-II image analysis system and then download small image files (640 by 480 pixels) to run on a PC. HEC has made many of their hydrologic programs to run on a PC.

In summary, these are the five main areas that we have found work the best for us in technology transfer. I am sure that remote sensing will continue to be used by the Districts and Divisions. This is evident from the number of image processing systems that are now available in the

Corps and also the future systems that are planned for the next few years. The decrease in prices for computers will also make the remote sensing technology affordable for the Districts. Software developers are making the image processing software easy to use and more interactive. This will also allow for more Corps users to integrate remote sensing data into their projects.

REMOTE SENSING TECHNOLOGY TRANSFER: A COMPLEX EXPERIENCE*

Jack Stoll

U.S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, Mississippi

---

*Abstract not available

DEMONSTRATING THE USE OF SHORE-BASED RADARS FOR SENSING COASTAL OCEAN PARAMETERS*

David Driver

Hydrologic Engineering Center
609 Second Street
Davis, CA 95616-4687

---

*Abstract not available

TECHNOLOGY TRANSFER OF THE CORPS' HYDROLOGIC MODELS

Arlen D. Feldman*

I. INTRODUCTION

The Hydrologic Engineering Center's, HEC, experiences in transferring hydrologic engineering software to the profession are presented in this paper. It describes several of the HEC's technology transfer activities and the ingredients of successful technology transfer. The paper also discusses several of HEC's successes and failures in technology transfer.

Three main activities are the essence of HEC's service to the Corps: research, technical assistance, and training, see Figure 1. The HEC's research activity is very applications oriented to the problems of the Corps' field offices. In those research activities, the HEC tries to develop generalized techniques to solve specific field problems. Then, those generalized methodologies or software can be applied to similar problems in other areas of the country. The research activities are most often performed in combination with technical assistance projects for the District offices. The first priority in HEC's technical assistance to field offices is for those projects related to the research needs. Thus, the research results are put to a practical field use as soon as they are developed. Research innovations are oftentimes developed right on that field project.

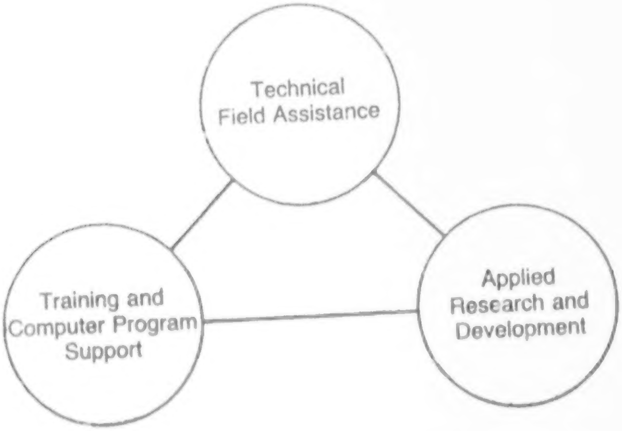


Figure 1. Activities of HEC

---

*Chief, Research Division, Hydrologic Engineering Center, U.S. Army Corps of Engineers, 609 Second Street, Davis, CA 95616. Presented at the Corps' Sixth Remote Sensing Symposium, Galveston, Texas, November 1987.

Technology transfer occurs during those technical assistance projects and in training courses which make use of the results. HEC presents formal courses through the Corps training program; students receive the benefits of both the research and the technical assistance programs in those courses (Bonner, 1984). Thus, the district personnel attending the training courses, the districts seeking technical assistance, and the research community are all interlinked.

The HEC seeks to bridge the gap between university-type basic research, and the practical needs of the Corps. Oftentimes the research results from the universities require practical testing before implementation at the field engineering level. As a result of trying to bridge this gap, HEC is often accused of being too practical by the academics, and too theoretical by the districts.

II. HEC TECHNOLOGY TRANSFER ACTIVITIES

There are five activities the HEC undertakes to perform its technology transfer: formal training; workshops; seminars; field implementation; and continuing support. The formal training is that of the Corps-wide short-course program. Those training courses evolve from work over the years on subjects of general need by the Corps' field offices. Oftentimes the formal training courses begin as seminars or workshops. Workshops are an informal or preliminary training course to meet a particularly timely field need. If there is enough need on a Corps-wide basis, the workshop becomes a part of the formal training program.

The earliest part of the technology transfer program often begins with a seminar. The seminars are an effort to bring together state-of-the-art technology and the needs of the Corps' field offices. Experts from universities, private industry, Corps offices and other Federal offices discuss their latest capabilities. Those capabilities are presented to a selected group of Corps field office representatives. The field offices also make presentations describing their particular hydrologic engineering problems. The intent of the seminar is to bring about a free exchange of ideas between the technology developers and the users.

The field implementation of the developed technology is an all-important link in its success. The HEC works closely with district and division offices to incorporate the newly developed technology directly within their operations (Johnson, 1981). This often involves HEC engineers working directly in the field offices. HEC and field personnel set up, test, and run the technology, e.g., a particular software program. Field implementation also includes the district personnel coming to HEC for more intensive training. The final ingredient of a successful technology transfer is the continuing support of the developed products. The HEC has maintained a software support service over the years to assist users of its computer programs. This continuing support or user service consists of direct responses to user inquiries by telephone or in writing. This continuing support is essential to the successful implementation of the computer programs. As a technology becomes more widespread and mature, the user support can be provided by other offices with the appropriate expertise.

III. INGREDIENTS OF SUCCESSFUL TECHNOLOGY TRANSFER

There are several ingredients for successful technology transfer. The first of which is that a need exists. Either the user recognizes that the need exists or the need is recognized by the R&D activity. There are different risks involved depending upon how the need is perceived. If the user identifies the need, then there is much less risk both to the user and the R&D activity. If the R&D lab identifies the need, there is more risk to successful field implementation. In this case, the lab must sell the technology; i.e., convince the field office that the new technology assists in performing their duties better than they are able to do without it.

The success of the technology transfer will greatly depend upon the resources of the user and the resources of the R&D lab. The management (in the field, in the labs, and in the general organization) is also a key element in the success of the technology transfer. One consideration for user resources is whether the user plans to develop an in-house capability or to contract. In either event the user must have a firm grasp on the technology. The only difference in doing the work by contract is that the user need not develop production resources.

In order for the user to effectively assimilate the technology, they must comprehend the technology, they must have the capacity to absorb the technology, and they must have the ability to apply the technology. The management resources of the user are key ingredients in the successful implementation of the technology. The local management must support new ideas and must be willing to take a risk in their implementation. These managers must be able to see, that is, be confident in, the long-term benefits to be derived from the technology.

The resources of the R&D lab, i.e., the experts, are also extremely important to the technology transfer. Those resources are important for the development of the technology as well as its implementation into the field setting. The management of the R&D activity must be flexible to take on new directions as directed by the field problems. They must support the innovation of their staff in developing the technology. The management must be innovative in their financing to carry over the R&D activities during difficult financial times. As mentioned previously, the lab and especially the technical experts need to be good salesmen to represent their products effectively to the field offices.

It is essential that the experts do not oversell the technology early in its development. They should let the technology grow as it begins to speak for itself through successful applications. The smallest successful application of a new product is the best recommendation there can be for that technology.

In order to be creditable salesmen, the experts must have a sound technical ability; and that ability must be very evident to the field offices. The experts need to be patient and understanding in order to appreciate fully the problems of the field personnel. They must see how the field personnel view the particular problems being solved. In order to implement this technology, the researchers also have to be good teachers. They teach the new users the capabilities and applicability of their products; then, they must follow-up to "make it work." The follow-up support and maintenance of the products are essential to the viability of the technology.

IV. ORGANIZATIONAL RESOURCES

The organization, i.e., the Corps of Engineers management, must be willing to fuel the development of the technology. The Corps does this now through their R&D program. It was very gratifying to hear the strong support for remote sensing technology expressed by the Chief of Engineers, General Heiberg, in his keynote address to this symposium. The organization must take special care to encourage a field application of the developing technology. That is, don't let the technology developers drift off by themselves to the so-called "ivory tower." In fact, the organization should require these field applications as the justification of continuing the technology development.

The organization should establish specific elements within its organization to support the technology that's created (Peters, 1980). There is no surer death for new technology than failure to support what is created. The Corps R&D labs and offices usually provide that support. If new technology comes from outside of the normal R&D laboratory system, then the organization must ensure that some elements within the lab, or within another part of the organization, are available to nurture and apply that new technology.

Demonstration projects often help to develop new technology. Such demonstration projects are usually at a larger scale and must seek funding from the general organization. In the case of the major demonstration projects, oftentimes there is such a large investment in the project that it almost always "succeeds" from the institutional stand point, but it may not accomplish much. Thus, it is especially important to involve the field offices so the technology development and application have a firm basis. Without the field implementation, such demonstration projects would find it difficult to be truly successful. With the field application and involvement, the technology can be successfully demonstrated and transferred.

V. GIVE TECHNOLOGY A HOME

It is essential to give a good home to the newly developed technology. The HEC has found this to be especially true of its software which has developed over the years (Eichert, 1983) That software can be likened to a person in many respects. During the software's infancy it needs much guidance to correct its errors and steer it to the correct solution. During its teenage years, the technology needs further guidance so the maturing technology is not misapplied. Also, as the technology receives more widespread application, new requirements for the software often occur. The key point is: software is a dynamic technology that must be corrected and developed throughout its life. During the adult years of the software, the organizational support must be there to answer the user's questions and continue to update the technology to the state-of-the-art.

The home for technology support must have staff with sufficient technical expertise to meet the users demands (Feldman, 1983). They provide support in three different ways: assess the applicability of software to different technical problems; provide program usage guidance and results interpretation; and correct errors and make modifications to the software. Oftentimes the users can only describe a particular technical problem hoping the support center will determine the best solution (e.g., computer program). Here, the support center must be well aware of a variety of technologies and be able to advise the user accordingly. When the user is applying the software, they need telephone access to the support center for specific information about how to use the software.

The last function of the support center is to correct errors in the technology (software). Almost every major new application of software requires some modification or error correction. The original software was developed to solve a particular problem; but, when it's applied to new and different problems, often the combinations of various capabilities do not work correctly.

An important means for the technology support center to communicate with its users is a newsletter. The HEC newsletter communicates information about new developments and error corrections in its software. When users discover errors or problems with the software, all known users of the program are so advised. So, either through these advisory notices and/or the newsletters, all of the users are made aware of the changes.

VI. SUCCESSFUL TECHNOLOGY TRANSFER

The most successful type of technology transfer is the automation of already accepted techniques. This was the case for most of HEC's rainfall-runoff models and river hydraulics models. This is also true of the flood frequency computation methods and the flood damage computations methods. In those cases, commonly used, well accepted, techniques were simply automated into a computer program. In this case, the developer doesn't have to fight the battle of a new technique. Two other examples of successful technology transfer are the development of HEC's water control software and the development of two-dimensional hydrodynamics software. These technologies branch out from the readily accepted techniques category into the use of new technologies. The water control software technology is a combination of previously accepted techniques and new technologies to communicate, display and analyze information.

The two-dimensional hydrodynamics technology is a new technology which was not possible with the past computational techniques. It requires the speed of modern digital computers. The theory of the hydrodynamics is well established, but the numerical approximations to make the computations feasible are new. In the case of the two-dimensional hydrodynamics, the HEC began with small applications in the field offices. The field engineers received training through direct application. Eventually the new technology became part of the regular formal training program.

Technology such as the two-dimensional hydrodynamics requires special user expertise. It's not a technology that any person who once ran a water surface profile can use. There is some discussion in the general literature whether such sophisticated technology should be transferred to the field engineers. Many people believe that such sophisticated technology should remain in the hands of the experts for application. There is some comparison here with the Corps' remote sensing program. Should the specialized image classification and remote sensing analysis techniques be transferred into the field offices, or should they remain within the specialized expertise of the R&D labs?

VII. FAILURES OR LIMITED-SUCCESS OF TECHNOLOGY TRANSFER

There are several aspects of technology and user/expert situations which may limit the success of technology transfer. If the technology is beyond the capability of the user, there is no chance that there can be effective use of the technology. As in the case of the computer software, it doesn't make any difference how sophisticated the model is, it's the expertise of the person applying the model that is most important.

Another pitfall of successful technology transfer is that the new technology requires doing business in a different way. That is, not doing the business in an accepted manner both in a technical sense and in the organizational sense. If a new technology requires different elements of the organization to interact, the organization must exert an extra effort to make it successful. This is more difficult than selling new technology to users within a single organizational unit.

The geographic information systems (GIS) technology proposed for the expanded floodplain management studies faced these organizational types of problems. The GIS approach requires the front-end development of a large database by several different organizational entities within a district office (Webb and Davis, 1978). It also required a significant effort from computer management to develop the database (also known as grid cell databank).

Insufficient support for a new technology will certainly doom it to failure; there were already several points made in this regard. Thus, the organization should establish a home to support the new technology. Successful technology transfer occurs when the field is involved throughout the development of the new technology. If the field does not participate, the new product will not be mature enough to be successfully transferred to the field. Lastly, there is the age-old problem of the researcher: be sure there is a problem to solve before developing the technology. If a new technology does a job better but is more costly and does more than is necessary, then, the user will have little incentive to make use of that technology.

VIII. SUMMARY

Technology transfer at the Hydrologic Engineering Center takes place in its reseach, technical assistance and training activities. The interlinkage of these activities is important both to the development and to the transfer of technology. HEC's five main technology transfer activities (formal training, workshops, seminars, field implementation, and continuing support) were described in relation to those main activities.

Ingredients for successful technology transfer were illustrated. High quality technical expertise is, of course, necessary for successful technology development and transfer; but, it is not sufficient. Successful technology transfer also requires organizational and managerial resources to open a receptive environment for the new technology. And, most importantly, new technology must be given a home and a firm support base. Continued support and development of new technology is necessary to keep it viable.

New technology will either go unused or, worse yet, be misused without successful technology transfer. The best technology (e.g., computer program) in the hands of an inexperienced user is not an advancement. The user must understand how the new technology relates to (simulates) the physical process being analyzed. Without that, the results are meaningless.

IX. REFERENCES

Bonner, Vernon R., 1984. "Evolution in Computer Program Causes Evolution in Training Needs: The Hydrologic Engineering Center Experience." Technical Paper No. 98, Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA.

Eichert, Bill S., 1983. "HEC Software Development and Support." Technical Paper No. 91, Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA.

Feldman, Arlen D., 1983. "Software Documentation and Support: HEC Experience." Frontiers of Hydraulic Engineering, American Society of Civil Engineers, New York, NY.

Johnson, William K., 1981. "Training the Practitioner: The Hydrologic Engineering Center Program." Technical Paper No. 86, Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA.

Peters, John C., 1980. "Institutional Support of Water Resource Models." Technical Paper No. 76, Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA.

Webb, R. Pat and Davis, Darryl W., 1978. "The Development and Servicing of Spatial Data Management Techniques." Technical Paper No. 55. Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA.

TECHNOLOGY TRANSFER: A PRESCRIPTION FOR SUCCESS*

Andy Bruzewicz

U. S. Army Engr. Dist., Rock Island
P.O. Box 2004
Clock Tower Building
Rock Island, IL 61204-2004

*Abstract not avaiable

A PROPOSED REMOTE SENSING ASSISTANCE CENTER FOR THE CORPS OF ENGINEERS*

Harlan L. McKim

U.S. Army Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, NH 03755-1290

*Abstract not available

ADDITIONAL POSTER SESSION PAPERS AND ABSTRACTS

WETLANDS MAPPING-SHREVEPORT, LOUISIANA, AIDED WITH INFRARED PHOTOGRAPHY

Manual Barnes

U.S. Army Corps of Engineers, Little Rock, AR

ABSTRACT

Civil works projects often interface with wetlands. Accurate mapping of these areas is required to comply with the Clean Water Act and the National Environmental Policy Act.

Infrared photography enhanced the accuracy and reduced the man-hours required to map wetlands associated with the U.S. Army Corps of Engineers Bayou Bodcau Flood Control Project near Shreveport, Louisiana. The wetland mapping procedure basically consisted of the following:

1. An aerial reconnaissance of the 40-mile long project area was made.
2. U.S.G.S. quadrangular maps were examined.
3. Infrared photography assisted in locating ground truthing transects.
4. The project area was ground verified via transects to determine soils, vegetation, and hydrologic information.
5. Infrared photography assisted in mapping wetlands between ground truthing locations.

QUICK RESPONSE MONITORING OF HURRICANE JUAN FLOODING IMPACTS IN LOUISIANA, UTILIZING NOAA/AVHRR SATELLITE IMAGERY

Robert H. Cunningham

Center for Wetland Resources, LSU,

and

Cecil W. Soileau

New Orleans District
U.S. Army Corps of Engineers

Donald R. Wiesnet

and

Morris Deutsch

Satellite Hydrology Associates, Vienna, VA

ABSTRACT

Hurricane Juan was a relatively weak storm but was an extremely unusual event in terms of duration over the same region. Juan's circulation began to directly affect Louisiana on October 26, 1985, and did not depart until the morning of October 31. The resulting combination of coastal flooding due to storm surge and heavy rainfalls produced record breaking high water levels at many coastal communities and wetland sites.

Extensive cloud cover precluded regional monitoring until November 6, when a cloud-free nighttime NOAA-9 AVHRR image was collecting, a week after flooding had peaked. Digital analysis of this thermal IR data revealed large warm areas of ponded water and saturated soils. A dry season nighttime thermal image (June 4, 1985) was composited with the November 6 post-flood image. The resulting thermal anomalies were classified as flooded areas.

Despite the 1km resolution inherent in NOAA/AVHRR data, the automated classification of flooded areas was found to be accurate when compared with inundation maps prepared by New Orleans District, Corps of Engineers. This innovative response to an operational need is believed to be the first use of AVHRR thermal IR multi-temporal composites for flood disaster studies. The large area of coverage of this sensor and its four times daily coverage, make it a superior tool for preliminary studies of hurricane of regional flooding.

ADVANCED IDENTIFICATION OF DISPOSAL AREAS

G. E. Justis
U.S. Army Corps of Engineers, Little Rock, AR.

BACKGROUND

The Corps of Engineers Section 404 involvement in the Faulkner Lake area began with two main events, the Eastbelt Freeway and the Faulkner Lake Drainage District improvement project, which occurred during the time period of 1976-1977. The impact of the freeway project has been the rapid increase in development pressure placed on Faulkner Lake and surrounding wetland areas. The most notable sign of early development pressure was the reactivation in 1976 of the Faulkner Lake Drainage District (FLDD). FLDD's intent was to drain much of Faulkner and much of the surrounding area. The Drainage District made an inquiry as to the necessity for a permit for rehabilitating and modifying drainage channels originally constructed in the early 1900's. Some of this work was performed on Ashley Bayou downstream of Faulkner Lake under authority of a nationwide general permit. Work was stopped by court order immediately downstream from Faulkner Lake in 1980. An application submitted in 1982 for a permit related to more extensive drainage work in Faulkner Lake and the other canals and laterals tributary to and downstream from Faulkner Lake was denied the Drainage District in 1983 primarily because of overriding adverse effects on wetlands and water quality of the area. The Drainage District reapplied in 1984 for a much scaled-down plan of improvement, that included channel improvements only in the immediate area of Rose City to provide urban drainage and flood control, and in May 1986, this permit was granted. Controls to minimize environmental damage were included as conditions to the permit.

Meanwhile permits for the Eastbelt Freeway (I-440) had been issued in 1976 and work was nearing completion by 1983. Completion of the freeway focused considerable commercial development attention on the large tracts of agricultural land with frontage and ready access to a portion of the interstate system. These events have led to an increase in applications for Section 404 permits. These applications have been processed for more localized projects in the Faulkner Lake area generally involving fills in wetlands for various types of development purposes. Depending on the circumstances of each case, some of these permits have been denied and some have been issued, but all have invariably been controversial (FLDD is a good example) and, involved long processing times. Development pressures continue to increase in the area, and in evaluating these applications the Corps, in its balanced approach, must consider not only the beneficial and adverse effects of each individual project, but the cumulative effects of all such projects on the interrelated water resources of this area. Hence, the need for an overall study of these resources and an organized and integrated approach to conducting the Section 404 permit program in the basin.

INTRODUCTION

The AIDA study as described at 40 CFR Section 230.80 was initially proposed to the Little Rock District Corps of Engineers by the U.S. Environmental Protection Agency, Region VI, in July 1986. The study was seen as mutually advantageous to both agencies and agreed to in September 1986. A public scoping meeting was held on November 6, 1986 which resulted in, among other things, the expansion of the study area to include the lower half of the drainage basin (an area serviced by the Old River Lake Drainage District). The basic goals of the study are to shorten permit processing times, reduce resource-consuming demands on regulatory personnel and budget and give the public a general outline of the wetland boundaries in the area which may discourage applications in sensitive areas.

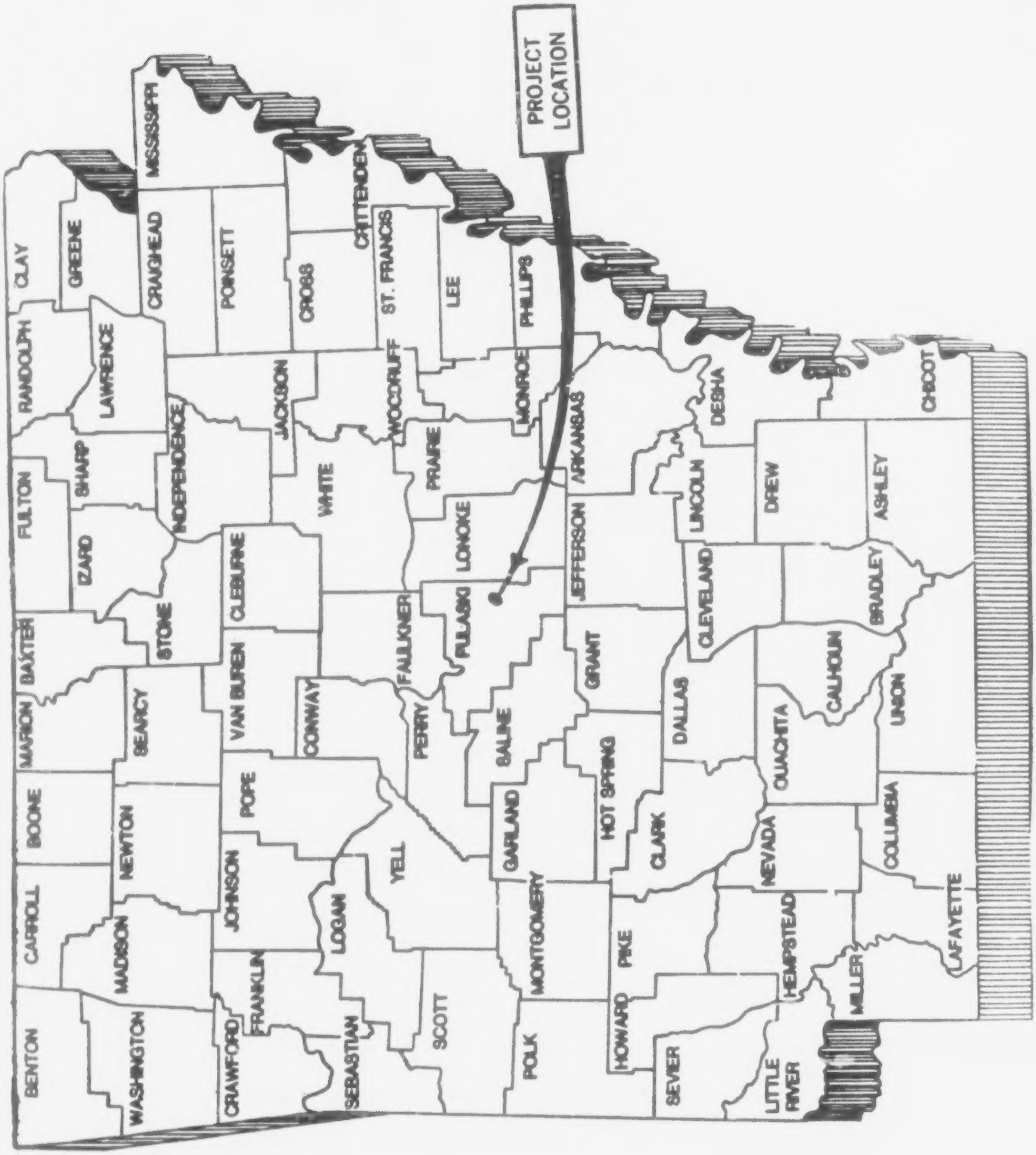
GENERAL APPROACH

Initial work elements which were considered were hydrology, water quality, ground water, wetland delineation, wetland evaluation, benthic species, aquatic species, bird species, migratory birds, and other wildlife. Elements which were considered and eliminated (if somewhat reluctantly) are as follows with the accompanying rationale: hydrologic studies and models, prohibitively expensive; Habitat Evaluation Procedure(HEP), prohibitively expensive for the amount of information gained when compared to the WET procedure; inclusion of the area riverward of the Arkansas River Levee, primarily influenced by the Arkansas River; inclusion of wetlands north of Hill Lake, separate drainage basin and in Vicksburg District. During consideration of the wetland delineation, the size of the drainage basin area, approximately 40 square miles, provided the motivation for utilizing color infrared (I.R.) aerial photograghy to assist in reducing the man-hours necessary to produce the final wetland boundary map product.

ACCOMPLISHMENTS/CONCLUSIONS

Unfortunately, the regulatory budget reduction problems encountered during the first months of 1987, later rigors of coordinating the transfer of funds among the COE, EPA and WES, and the scheduling of WES's project priorities, delayed the study. The good news is that the study was started on October 19, 1987. We optimistically expect the study to be concluded by July 1988 with positive results, i.e. a developed policy which will reduce application processing times for this general area. We fully expect that the use of the color I.R. photograghy will provide significant reductions in the time spent ground truthing the photograghs and making wetland delineation extrapolations. Hopefully, the results of the completed study and the benefits derived from the aerial photography will be presentable for next year's symposium.

ARKANSAS
RIVER
YOUNG
HILL
BIG ROCK
Willow Beach Lake
Georgetown Lake
SCALE 1:24 000
CONTOUR INTERVAL 5 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929
by the Geological Survey


PROJECT LOCATION
BENTON
WASHINGTON
CARROLL
MADISON
BOONE
NEWTON
MARION
BAXTER
SEARCY
FULTON
IZARD
SHARP
STONE
RANDOLPH
LAWRENCE
CLAY
GREENE
CRAIGHEAD
MISSISSIPPI
POINSETT
CROSS
CRITTENDEN
ST. FRANCIS
LEE
PHILLIPS
INDEPENDENCE
JACKSON
WOODRUFF
MONROE
CLEBURNE
WHITE
PRAIRIE
ARKANSAS
VAN BUREN
CONWAY
FAULKNER
LONOKE
PULASKI
JEFFERSON
LINCOLN
DESHA
DREW
CHICOT
ASHLEY
CRAWFORD
FRANKLIN
JOHNSON
POPE
LOGAN
YELL
PERRY
SEBASTIAN
SCOTT
SALINE
GARLAND
GRANT
HOT SPRING
CLEVELAND
BRADLEY
DALLAS
CALHOUN
OUACHITA
UNION
POLK
MONTGOMERY
HOWARD
PIKE
CLARK
SEVIER
LITTLE RIVER
HEMPSTEAD
NEVADA
COLUMBIA
MILLER
LAFAYETTE

THE USE OF SPOT AND TM IMAGES IN DETERMINING WATER QUALITY AT SAYLORVILLE LAKE RESERVOIR, IOWA

Cynthia A. Abrahamson

and

Clinton A. Beckert

and

Andrew J. Bruzewicz

U.S. Army Corps of Engineers, Rock Island District
Clock Tower Building - P.O. Box 2004, Rock Island, IL

Nancy LaPotin

and

Carolyn J. Merry

U.S. Army Cold Regions Research & Engineering Laboratory
72 Lyme Road, Hanover, NH

ABSTRACT

Given the cost of in situ measurement of water quality parameters and the increased emphasis on obtaining reliable water quality data, it would be useful and cost effective if broad aerial coverage could be obtained at low cost per unit area. An ideal situation would enable meaningful contouring of data for parameters of interest.

Initial work done with Multispectral Scanner (MSS) data from Landsats 1-3 has indicated that correlation exists between several water quality

parameters and reflectance data measured from satellite altitudes. In view of the increased spatial, spectral, and radiometric resolution of the Thematic Mapper (TM) and Systeme Probatoire d'Observation de la Terre (SPOT) sensors, the Rock Island District (NCR) and the Cold Regions Research and Engineering Laboratory (CRREL) have undertaken a joint study at the Saylorville Lake Reservoir, Iowa, to determine the utility of these sensing systems in analyzing selected water quality parameters: chlorophyll a, organics, secchi depth, nitrate, and phosphate. Previous work indicates limited success with parameters of inherent interest (e.g., turbidity) and those which may be harbingers of evolving problems (e.g., more frequent algal blooms).

TM and SPOT images will be acquired in June 1987 and samples will be taken at five locations along each of two transects. The image processing capabilities available in the Geographic Resources Analysis Support System (GRASS) software package, which is being run at NCR on a MASSCOMP(1) supermicrocomputer, will be used. These data will be combined with the analytical results of the sampling and models will be developed to determine the relationship between the reflectance data and the in situ measurements. A second data set will be taken and another set of images acquired during June 1988. One set of samples will be used to calibrate the models, and a second set to test them. For those models with sufficient explanatory pwoer, contouring of parameters providing important water quality data will be possible.

POCONO WETLANDS STUDY SUMMARY

Peter M. Stokely

The Bionetics Corporation
P.O. Box 1575, Vint Hill Farms Station, Warrenton, VA

ABSTRACT

Under jurisdiction of Section 404 of the Clean Water Act as it applies to wetlands adjacent to navigable waters, a large photo interpretive and computer digitizing project was accomplished by the Environmental Protection Agency's Environmental Photographic Interpretation Center (EPA/EPIC) a branch of the Advanced Monitoring Systems Division, Environmental Monitoring Systems Laboratory in Las Vegas, Neveda. This project was undertaken at the request of the Environmental Protection Agency Region 3.

The northeastern portion of Pennsylvania contains the largest concentration of wetlands in the state. These wetlands are in danger of severe degradation by man-made encroachments. A study of the aerial extent of these wetlands, an inventory of their numbers, and an exact geo-referencing of their locations and nature of man-made encroachments impacting the wetlands was also performed. Of particular interest to this study is the location and quantification of peat mines present today and identification of those wetlands which have the potential to be exploited for peat mining.

Using aerial photography and U.S. Fish and Wildlife Service National Wetland Inventory (NWI) maps, EPIC generated a map base product. This product is being used as a baseline for interagency field work, for wildlife and natural resources evaluation, and for formulation of a regional wetlands policy in support of the Advanced Identification effort under the Clean Water Act Section 404(C). The study area occupies a total of 80 U.S. Geological Survey (USGS) quadrangles.

Inventory of Resource

Using the NWI maps as the source of information, all wetlands over one acre were delineated and numbered from north to south, east tc west for each quadrangle in the study area. These delineated wetlands were then digitized in order to obtain areal measurements and exact geo-referencing in the UTM coordinate system for each wetland. The system employed for this is a Cala Graphics Interactive Analysis System (IAS). The end result is an measurements, and wetlands locations accurately recorded in the UTM coordinate system. All of the digitized information is stored on magnetic tape.

*Worked performed under contract #68-03-0361 for the Environmental Photographic Interpretation Center, Advanced Monitoring Systems Division Environmental Monitoring Systems Laboratory, Las Vegas, NV.

A subtrack of the inventory was to flag, measure and record the location of those wetlands or portions thereof that were classified as having an acid water regime by the NWI. The acid modifer was used as an indicator of those wetlands which potentially contain exploitable peat deposits.

Encroachment Update and Mapping

Used standard aerial photointerpretation techniques, spring of 1979 optical bar photography covering the study area was searched for man-made encroachments that were not shown on the base map. Encroachments included: housing tracts, commercial development, impoundments, landfills, other fill areas, ditching, drainage, farming, peat mines and any other man-made encroachment into or near enough to impact the region's wetlands. These encroachments were classified, delineated, measured, and their locations recorded in the UTM coordinate system.

Summer optical bar aerial photography from 1983 and 1984 was also analyzed in a similar manner to update the extent and nature of man-made encroachment into the Pocono wetlands. Changes in the extent of previously noted encroachments and the identification of new encroachments were classified, delineated, measured, and these locations recorded in the UTM coordinate system.

Products

Maps (1:24,000)

This computer digitized and stored map data was then plotted in a series of three overlays to fit standard USGS 1:24,000 quadrangles covering the study area. The three overlays depicted the: 1) delineated and numbered wetlands, 2) nature and extent of encroachments observed in 1979, and 3) nature and extent of encroachments observed in 1979, and 3) nature and extent of encroachments observed in 1983/1984. Printouts of the wetland acreages and associated encroachments' acres accompanied each map. This product of 80 quadrangles was incrementally delivered to EPA Region 3' Wetland and Marine Policy section.

Summary Map (1:250,000)

The delineated wetland overlays for all 80 quadrangles were merged by the computer onto three USGS 1:250,000 scale maps that cover the study area. One wetland overlay and a quadrangle and county locator overlay were produced and overlaid to the 1:250,000 scale maps. This product provides an overall view of the Pocono region's wetlands, counties and quadrangles.

APPLYING SPACE-AGE TECHNOLOGIES TO WATER DEVELOPMENT IN ARID AREAS

Dr. Farouk El-Baz

Director, Boston University Remote Sensing Center,

and

Robert A. Bisson

Chief Executive Officer, BCI Geonetics, Inc.

ABSTRACT

Ground-water exploration in arid regions is a complex process, dedicated by a most demanding hydrogeologic environment. The lack of (and poorly understood regional variances in) precipitation data, along with high potential evaporation rates and variable transpiration, relate in obscure ways to ground-water, recharge, storage and transport and create a singularly complex environment, which results in simplistic attempts to find major water sources. In arid areas phreatic aquifers are typically dry during much on the year, or possess water at such depth that development is not economically feasible. Often, where ground-water is found in arid climes, it is saline, due to the high evaporation rates found in a desert climate and, in certain locations (such as near the Red Sea) from transport of the ground-water through salt deposits. Therefore, traditional geomorphic and hydrologic techniques, often used successfully to find water in humid or temperate climates are, by themselves, inadequate and ineffectual when applied in an arid region.

In order to gain a practical knowledge of major, complex systems of alluvial and bedrock aquifers and to circumvent the problems associated with shallow, intermittent and often saline ground-water sources existing in arid environments, a exploration program must begin with reliable quantification of regional hydrogeologic characteristics, not simply theoretical "basins" or those limited areas studied by previous investigations. Furthermore, broader categories of aquifers must be

sought. For example, in arid zones, prolific aquifers exist in porous and permeable sedimentary formations as well as in fractured basement rock.

Indeed, much new ground-water is to be found in the fractures and fissures created by tectonic movements of the earth in both consolidated sediments and in basement complexes. Furthermore, these semi-discreet units are often hydraulically interconnected and active recharge may be available to these voids from remote sources tens or even hundreds of miles distant. These factors are simply not considered in local, hydrogeologic basin models.

One of the primary goals of large regional ground-water mapping programs must be to evaluate the hydraulic relationship among these regional aquifer systems and subsystems in order to effectively tap the most productive parts of regional water supplies, while conserving the resource through induced infiltration and controlled evaporation.

An accurate depiction of the hydrogeologic peculiarities of arid zones absolutely requires a very sophisticated exploration program, (as opposed to a hydrogeologic "study"). The exploration process must combine advanced techniques of remote sensing, structural geologic analysis of bedrock fracture fabric and high resolution geophysical surveys, to locate the best possible water supplies.

The authors will describe the methodology which they have employed to map and discover water in complex, arid geologic terrains. The presentation will focus on work accomplished in Egypt and Somalia.

DETERMINATION OF CRITICAL EROSION AREAS WITHIN AN URBAN WATERSHED USING LANDSAT TM AND THE UNIVERSAL SOIL LOSS EQUATION

Ken M. Morgan

and

Rick Sinclair

and

David Koger

Center for Remote Sensing
Texas Christian University, Fort Worth, TX

ABSTRACT

Landsat Thematic Mapper (TM) data and the Universal Soil Loss Equation (USLE) were incorporated into a geographic information system (GIS) to determine land use, quantify areawide soil losses, and locate critical erosion sites in the Lake Arlington watershed in North Central Texas. Our remote sensing analysis showed a 41% increase in areawide soil losses in the watershed over a four year period. The increase was due primarily to unprotected urban construction sites and long term fallow agricultural land. These critical erosion sites (exceeding 15 t/a/yr) were color-coded and located on the imagery as part of the permanent data base for watershed management by the City of Arlington.

Our study demonstrates the usefulness of integrating satellite data with a GIS for the purposes of monitoring land use changes that affect areawide soil losses. When used properly, Landsat TM imagery can be an integral part of watershed programs concerned with land use and soil loss management.

CONCEPT FOR A DIGITAL FLOOD HAZARD DATA BASE

Daniel M. Cotter

Project Engineer
Federal Emergency Management Agency
Washington, DC,

and

Richard K. Campbell

Department Head, Computer Mapping Greenhorne & O'Mara, Inc.
9001 Edmonston Road, Greenbelt, MD

ABSTRACT

The Federal Emergency Management Agency (FEMA) is currently assessing the possibility of supplementing hardcopy flood hazard mapping with digital data. Digital flood hazard data would support the National Flood Insurance Program by facilitating enhanced Federal, state, and local land use administration, risk assessment, and engineering tasks related to flood damage mitigation. Initial studies towards developing a digital flood hazard map data base indicate that such an effort is only viable if the digital flood hazard data can by incorporated into multi-purpose Geographic Information Systems (GIS's). The FEMA Integrated Emergency Management Information System supported by U.S. Geological Survey 1:100,000 scale digital base map data can provide ready user access to develop a digital flood hazard map data base, and discusses the possibilities for the automated dissemination, storage, and update of these data.

COMPUTING, DIGITIZING AND MAPPING AREAS FROM AIRCRAFT PHOTOGRAPHY ON A MICROCOMPUTER SYSTEM.

Pat O'Neil

U.S. Geological Service, Information & Data Services
Applications Assistance Facility, Building 3101, NSTL, MS

ABSTRACT

Most typical mapping strategies of natural resource planners who frequent the U.S. Geological Survey's National Mapping Division. Applications Assistance Facility are to take color infrared prints or transparencies and delineate interpreted areas to to a preferred scale or map base scale. It would be extremely useful at this stage to be able to simultaneously planimeter and digitize newly created maps by microcomputer technology for final presentation and to derive tabular statistics for each mapping category. A procedure for computing, digitalizing and mapping areas from aircraft photography on a microcomputer system using Measuregraph and AutoCAD software has been accomplished at the Applications Assistance Facility.

REMOTE SENSING FOR WATERSHED MANAGEMENT

Denice Shaw

Institute of Applied Sciences
North Texas State University

ABSTRACT

Landsat MSS data was used in conjunction with the universal soil loss equation (USLE) to predict sediment loading in four major watersheds regulated by the City of Dallas Water Utilities Agency. Digital MSS data were obtained from the summers of 1974, 1977 and 1986. Each image was classified into its respective land use categories and georeferenced to Universal Transverse Mercator (UTM) map projection. Additional digital ancillary spatial information was also added.

The universal soil loss equatition (USLE) was applied to predict soil loss in the watersheds. The following factors were incorporated into the analyses: rainfall values, soil erodability and topography. The potential average annual soil loss (tons/acre/year) was predicted on a pixel by pixel basis. Data were categorized into areas with; low (≤ 4), moderate (≤ 7) high (≤ 14) and very high (≤ 14) potential for soil loss. Those areas designated as very high were considered to be "critical".

A time series analysis was conducted (i.e. 1974, 1977, 1986) in order to identify areas of landuse changes and from this, predict areas that are moving into the "critical" phase.

THE ROLE OF REMOTE SENSING AND GIS IN DETERMINING BANK PROTECTION PROGRAM EFFECTIVENESS

Phillip E. Orlowski

Portland District, U.S. Army Corps of Engineers

ABSTRACT

The U.S. Army Corps of Engineers, Portland District has constructed and is responsible for over 93 miles of bank protection structures in the Willamette River Basin, Oregon. These structures control the river by limiting bank erosion. In 1986, the Portland District began a study to assess the effectiveness of the current bank protection program in the Willamette Basin by estimating future erosion, identifying alternative bank protection methods to lower costs and reduce environmental impacts, and examining ways of increasing benefits of bank protection. A pilot study was initiated to collect baseline data on the lower 20 river miles of the South Santiam River, Oregon, investigate cumulative impacts (physical, economic, and environmental) of bank protection by comparing revetted and unrevetted reaches, and establish a .methodology that could be applied to other areas or to the entire Basin. Remote sensing and geographic information system (GIS) technology contributed significantly to these tasks.

Historical maps and aerial photography from 1852 to 1986 provided the majority of data for the mapping component of the study. Channel locations and 15 classes of land cover were mapped at a scale of 1:12000 for up to 12 dates within that time period. Sample reaches from the 20 river mile study are are presenting primarily revetted and unrevetted conditions were selected to provide a detailed focus on revetment impacts. Individual dates of land cover and channel location were digitized and stored as GIS files. GIS analyses focused on various combinations of dates and produced the following information: identification of the 130-year active channel zone; rates of vegetative succession; and an inventory of land cover within future erosion risk zones, to which economic value was attached for an assessment of erosion losses. A review of the aerial photography also provided an historical account of river response to revetments. Various map products were generated for graphic display of results and distributed to study team members.

INTEGRATED SATELLITE IMAGERY AND CADD FOR WATERSHED MANAGEMENT, 404 PERMITTING AND ENVIRONMENTAL IMPACT ASSESSMENT

Aubie J. Oslin, Ph.D.
Albert H. Halff Associates, Inc.
8616 Northwest Plaza Drive
Dallas, Texas 75225

ABSTRACT

Landsat TM satellite data has been used to develop existing land cover information along the West, Elm and East Forks of the Trinity River and the Denton Creek and White Rock Creek watersheds in North Central Texas. The GIS raster (grid) data are combined with Computer Aided Drafting/Design (CADD) vector data to evaluate change in rapidly developing watersheds and assess the environmental impact of development projects. Quantitative information derived from the analysis is being used in the 404 Permit application and mitigation process, environmental impact assessments, Flood Insurance Studies, and watershed management. Three studies are described whereby the combination of raster and vector data facilitated analysis: (1) Environmental Impact Assessment for the Proposed North Beltway in Tarrant and Denton Counties; (2) 404 Permitting and Mitigation for a Proposed 2700 Acre Development on the West Fork of the Trinity River; and (3) White Rock Creek Watershed and Flood Plain Management. These projects illustrate the practical application of remote sensing, CADD, and GIS for current engineering and environmental studies.

INTRODUCTION

Satellite imagery and remotely sensed data have been used by the water resources community for many years (Deutsch et al. 1981). Hydrology and hydraulic studies continue to adapt and exploit the technology as new sources of data become available. Several studies have reported favorable results when a remote sensing approach was compared to conventional methods for determining the land cover component in hydrology models (Cermak et al. 1981, Rango 1985, Draper and Rao 1986). Remote sensing has also been used successfully in sediment erosion and bank erosion studies (Rahm 1981, Gersmehl 1987).

Recently, there has been increased interest in the engineering community to utilize remote sensing and Geographic Information Systems (GIS) to facilitate feasibility and environmental studies. Vector based CADD systems have been used by engineers for several years. A great amount of design and map information exists in this digital form. Vector graphic display and storage is most efficient when the spatial conditions are accurately defined as lines, points, or polygons with definite edges, such as property parcels, jurisdictions, and the center lines of roads, pipelines or streams. A vector based GIS is useful for many applications where these features are mapped and the spatial relationship analyzed (Talbot 1986, Tomaselli and Gilhousen 1987).

A raster based GIS is useful for managing and analyzing a database that relies upon remote sensing as a principal source of database development and update. Raster GIS has been used to evaluate change in land use (Oslin 1987, Goodenough 1988), to model non-point source pollution potential (Gilliland and Potter 1987), and to map erodible soils using the Universal Soil Loss Equation (Johannsen 1983, Gersmehl 1987, Crowder 1987).

Geographic Information Systems are being developed using both vector and raster data. The user community is thus promoting the development of integrated systems that incorporate the best features of each data form (Arnoff and Parliament 1987, Logan and Bryant 1987, Maffini 1987, Robinson and Frank 1987). This paper presents three studies whereby GIS is used to combine raster and vector data, as well as facilitate quantitative analysis. These projects illustrate the practical application of remote sensing, CADD, and GIS development for current engineering and environmental studies. The following studies are described:

(1) Environmental Impact Assessment for the Proposed North Beltway in Tarrant and Denton Counties,

(2) 404 Permitting and Mitigation for a Proposed 2700 Acre Development on the West Fork of the Trinity River, and

(3) White Rock Creek Watershed and Flood Plain Management.

METHOD

A similar method was employed for each of the studies. A Landsat Thematic Mapper (TM) satellite image was used to produce the land cover component of a raster GIS. Remote sensing data and the raster GIS were processed using Earth Resources Data Analysis System (ERDAS) software. Sub-scenes covering the particular area of interest were taken from the satellite image. Bands 1, 2, 3, 4, 5, and 7 were subset for subsequent analysis.

Both supervised and unsupervised techniques were employed to classify the sub-scenes. The raw image and the classified products were registered to state plane coordinates by one of two methods. Either ground control points from the image were matched to points on USGS 7.5 minute quadrangle maps or the processed image was rectified to a GIS built to accommodate the geodetic grid of the CADD design file.

Intergraph CADD design files were translated to a Standard Interchange Format (SIF) so that the vector data could be included in the analysis. Knowledge of (1) the Intergraph units of resolution, (2) the original scale and projection of the digitized maps, and (3) the attribute interpretation of Intergraph graphic elements were all essential for the successful conversion of the vector data. Once the Intergraph vector data was converted to this ASCII exchange format, the graphic elements were gridded to the raster GIS. In this manner, Intergraph vector data was combined with the raster data, then used to summarize cultural and natural resource information developed in the GIS.

CASE ONE: ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED NORTH BELTWAY IN TARRANT AND DENTON COUNTIES

The proposed North Beltway is a 12.8 mile highway project which includes: (1) the improvement of State Highway 114 to a controlled-access urban standard freeway in Tarrant and Denton Counties, (2) a north bypass of the City of Roanoke, and (3) construction of a controlled-access urban standard freeway spur from State Highway 114 to Interstate Highway 35W in Tarrant County. The proposed route will be an integral part of a future loop around the City of Fort Worth and will provide North Fort Worth with direct access to DFW International Airport.

Existing land use in the North Beltway corridor is primarily urban at the east end, changing to agricultural and low density residential as it progresses westward. The corridor is generally in transition from rural to urban use. North Tarrant County is rapidly becoming urban with development pushing northward from the Fort Worth metropolitan area and westward from the Grapevine and Southlake area.

Although there are no significant impacts upon endangered or rare species, the conservation of natural resources has been an important consideration in the design and planning of the freeway. A landscape and beautification plan using native Texas plants is proposed for the project. Most of the land is dedicated to agricultural land use at present. Narrow creek channels are characteristic of the flood plains encountered and no designated wetland areas are impacted.

A sub-scene covering the study area was taken from a 1986 Landsat TM image. This image was classified to produce a seven category class map, Figure 1. In order to evaluate the proposed route impact on existing land cover, the proposed design was set into the raster GIS and given a 350 ft. right of way. Land cover impacted by the route was then summarized. Table 1 provides a summary of the percent of each cover type impacted by the recommended route of the North Beltway Freeway.

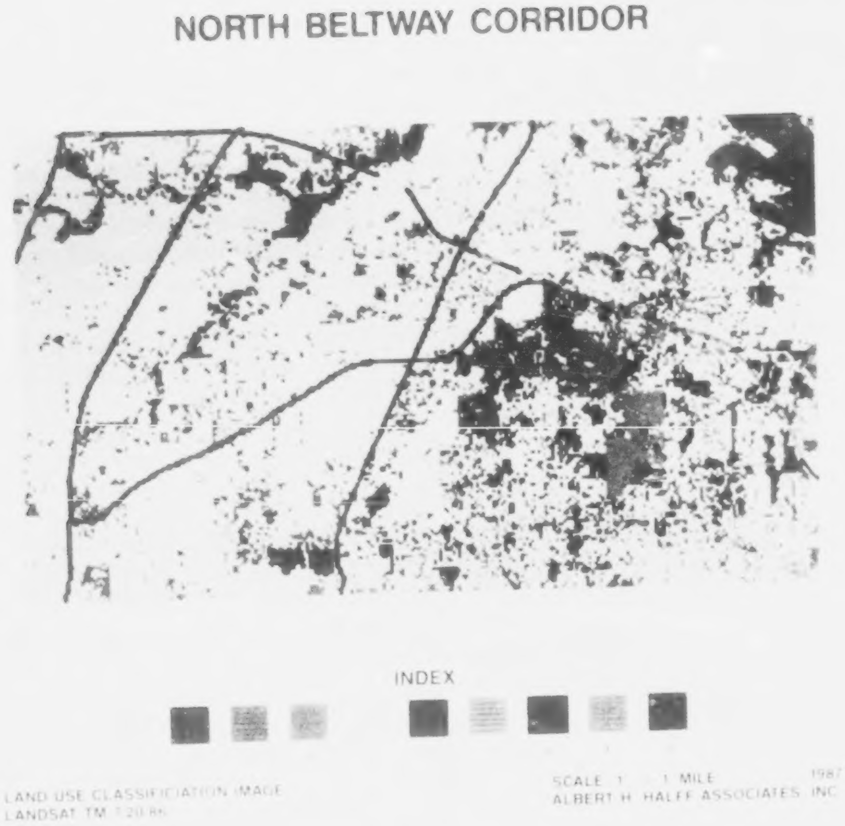

NORTH BELTWAY CORRIDOR
INDEX
LAND USE CLASSIFICIATION IMAGE
LANDSAT TM 1.20.86
SCALE 1 1 MILE
1987
ALBERT H. HALFF ASSOCIATES, INC.

FIGURE 1 - LAND USE CLASS MAP CREATED FOR THE ENVIRONMENTAL IMPACT ASSESSMENT OF THE NORTH BELTWAY IN TARRANT AND DENTON COUNTIES, TEXAS.

TABLE 1 - SUMMARY OF LAND COVER IMPACTED BY THE RECOMMENDED ALIGNMENT OF THE NORTH BELTWAY FREEWAY.

	Class Name	Spur Freeway Segment %	S.H. 114 Segment %	Roanoke Bypass %	Total North Beltway %
1	Agricultural Fields	86.63	39.03	73.57	69.57
2	Tree Canopy	1.41	4.71	0.49	2.23
3	Disturbed or Developing Land	5.17	4.93	7.58	5.57
4	Lawn and Improved Pasture	2.19	2.93	1.25	2.23
5	Impervious/Packed Surface	2.38	17.18	8.55	8.10
6	Water	0.70	0.04	0.00	0.37
7	Shallow Water	0.76	0.22	0.42	0.53
8	Existing Highway Right-Of-Way	0.76	30.95	8.14	11.40
9	S.H. 114 Segment	0	100	0	30.49
10	Spur Freeway Segment	100	0	0	50.03
11	Roanoke Bypass Segment	0	0	100	19.48

CASE TWO: 404 PERMITTING AND MITIGATION FOR A PROPOSED 2700 ACRE DEVELOPMENT ON THE WEST FORK OF THE TRINITY RIVER

The proposed TXI-Brookhollow development project occupies approximately 2700 acres along the West Fork of the Trinity River. Hardwood tree canopy and extensive wetland conditions required careful design of fill and channel improvements throughout the project area.

A wildlife mitigation plan was developed in order to adequately compensate for lost fish and wildlife resources. The wildlife mitigation plan was developed in conjunction with the U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, and U.S. Environmental Protection Agency. Representatives from the various agencies met with Halff Associates' environmental scientists to develop and optimize a wildlife mitigation plan. The initial task for assessing the wildlife resources impacted by the project was to evaluate the various habitats under existing and proposed conditions.

A supervised classification was performed using a 1986 Landsat TM image to delineate land cover (habitat) types. Figure 2 illustrates the existing and proposed land cover in and around the project site. Design information and property boundaries were converted to raster form so that land cover impacted by the project could be evaluated. Table 2 lists acreage of existing land cover within the property boundaries, as well as acreage of proposed land cover conditions after project development. Land cover impacted by each of the design elements was evaluated. Because of the extensive wetlands and hardwood tree canopy impacted by the project a detailed mitigation plan was developed.

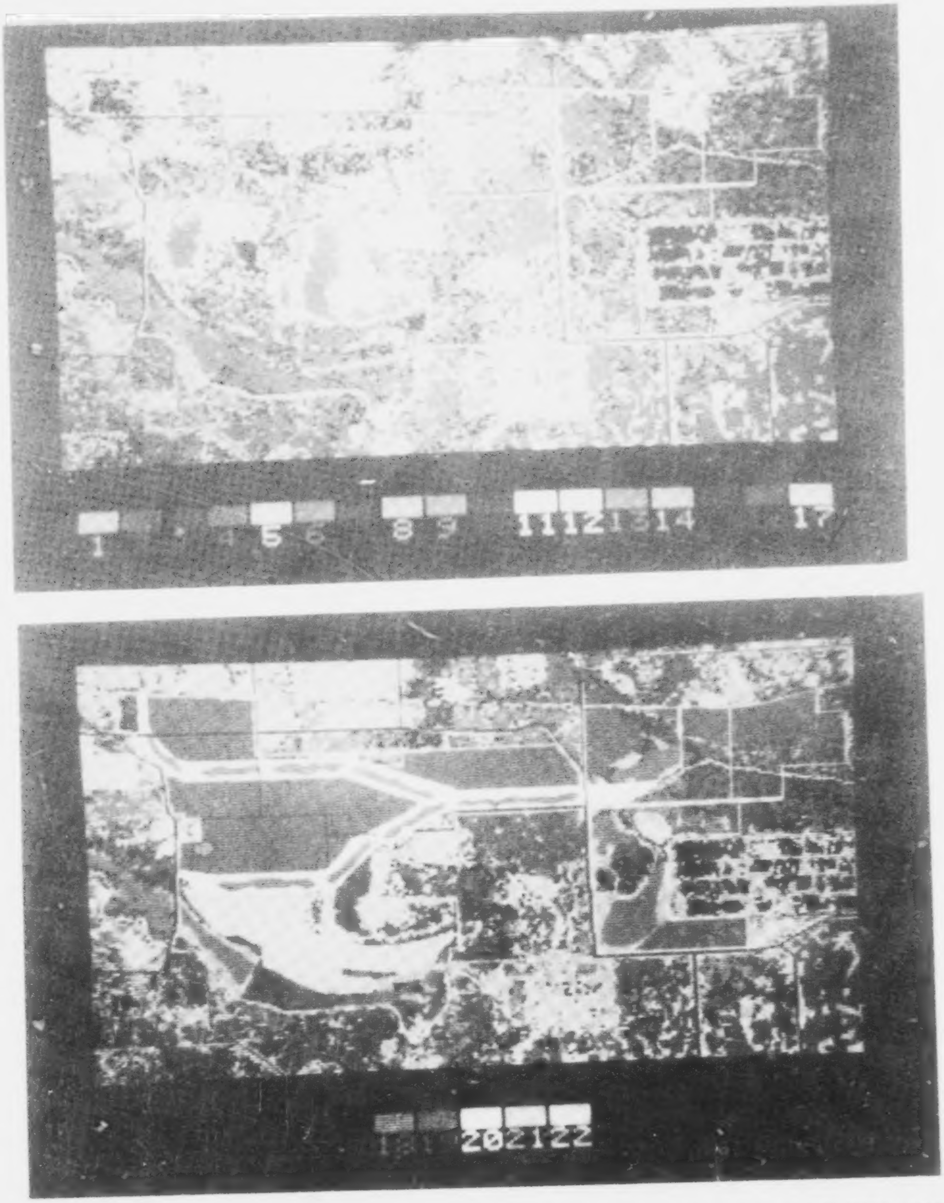


FIGURE 2 - EXISTING AND PROPOSED LAND COVER CONDITIONS PRODUCED FROM THE COMBINATION OF LANDSAT TM DATA AND CADD DESIGN FILES FOR THE TXI-BROOKHOLLOW PROJECT.

TABLE 2 - APPROXIMATE ACREAGE OF EXISTING AND PROPOSED LAND COVER WITHIN THE TXI BROOKHOLLOW PROPERTY BOUNDARIES.

Existing	Acres	Proposed	Acres	
1 Roads/Impervious Surfaces	214	1 Roads/Impervious Surfaces	12	
2 Residential	0	2 Residential	0	
3 Turbid Water	16	3 Turbid Water	0	
4 Deep Water	133	4 Deep Water	72	
5 Shallow Water	254	5 Shallow Water (Existing)	79	
6 Standing Water Willow	245	6 Standing Water Willow	50	(72)*
7 Herbaceous Marsh	178	7 Herbaceous Marsh	37	(36)*
8 Willow/Cottonwood	174	8 Willow/Cottonwood	54	(20)*
9 HDW/Cedar Elm-Ash	349	9 HDW/Cedar Elm-Ash	208	(50)*
10 HDW/Pecan-Oak	245	10 HDW/Pecan-Oak	110	(32)*
11 Scraped/Bare Ground	27	11 Scraped/Bare Ground	0	(1)*
12 Disturbed/Vegetated	241	12 Disturbed/Vegetated	32	(19)*
13 Old Field/Herb-Forb	362	13 Old Field/Herb-Forb	60	(12)*
14 Grass	244	14 Grass	61	(8)*
15 Sludge Field	0	15 Sludge Field	0	
		16 Roads	54	
		17 TXI Property Boundary	0	
		18 Proposed Shallow Lakes	158	
		19 Proposed Fill Areas	938	
		20 Overflow Swale & Improved Channel	318**	
		21 Proposed Hardwood Plantings	131	
		22 Improved Habitat	308	
Total Acreage	2682	Total Acreage	2682	

* Acreage that lies within the area of improved habitat

** Of this 318 acres listed for the proposed overflow swale and Walker Channel improvements, approximately 120 acres are estimated to be depressions of shallow water.

Figure 3 illustrates the proposed mitigation plan developed in conjunction with the U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, and the Environmental Protection Agency. The mitigation plan proposes the creation of additional wetland lakes, which would provide shallow water wetland habitat. A few small islands would be created within the lake area to increase the shoreline area and thus provide isolated sites for wildlife propagation.

Approximately 130 acres of hardwood trees would be planted around the proposed lakes and in open fields, as shown in Figure 2. There would be selective bank and shoreline creation, which would flatten steep banks and increase the area available for establishing wetland communities. Based on field investigations, a few gravel pits could be connected and some banks would be improved within a 308-acre area designated as improved habitat.

There would be approximately 158 acres of new shallow lakes within the flood plain and approximately 120 acres of shallow lakes within the overflow swale. The 318-acre habitat within the Walker Branch channel and the overflow swale would be mowed annually by the owner (levee district). The remaining 1426 acres of open space would be deed-restricted to prevent future development, thus insuring the land would be preserved for wildlife habitat.

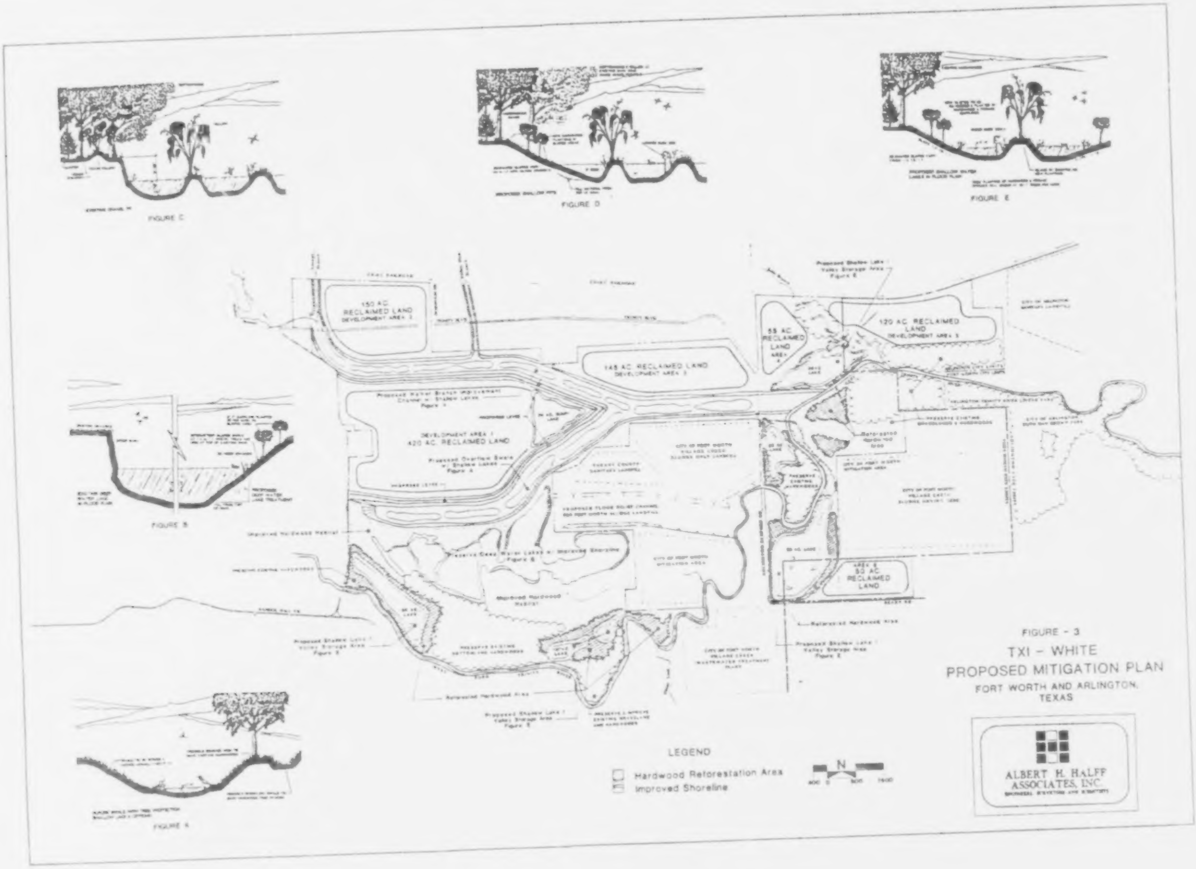


FIGURE C
FIGURE D
FIGURE E
FIGURE B
FIGURE A
150 AC. RECLAIMED LAND DEVELOPMENT AREA 2
148 AC. RECLAIMED LAND DEVELOPMENT AREA 3
55 AC. RECLAIMED LAND AREA 4
120 AC. RECLAIMED LAND DEVELOPMENT AREA 5
DEVELOPMENT AREA 1 420 AC. RECLAIMED LAND
Proposed Overflow Swale w/ Shallow Lakes Figure A
AREA 6 50 AC. RECLAIMED LAND
Improved Hardwood Habitat
Reforested Hardwood Area
FIGURE - 3
TXI - WHITE
PROPOSED MITIGATION PLAN
FORT WORTH AND ARLINGTON, TEXAS
LEGEND
Hardwood Reforestation Area
Improved Shoreline
N
ALBERT H. HALFF ASSOCIATES, INC.

FIGURE 3 - PROPOSED MITIGATION PLAN DEVELOPED IN CONJUNCTION WITH THE 404 PERMIT APPLICATION FOR THE TXI-BROOKHOLLOW PROJECT.

CASE THREE: WHITE ROCK CREEK WATERSHED AND FLOOD PLAIN MANAGEMENT

The upper White Rock Creek watershed is one of the most rapidly developing basins in the Dallas/Fort Worth metropolitan area. It extends from north Dallas into Plano, and includes the City of Frisco and the Town of Addison. Two earlier reports, a Flood Plain Information Report by Halff Associates in 1975 and the FEMA Flood Insurance Study of 1977, produced stormwater runoff volumes based on proposed and existing 1970 land-use conditions for the basin. The watershed has developed with greater densities and with larger areas of imperviousness than was predicted in the early studies. This development pattern has created increased flood flows in the lower part of the basin. For this reason, the Cities of Plano and Dallas joined in a cooperative effort to develop a flood-plain management plan.

A raster GIS was developed to evaluate changes in land use. The GIS was built to accommodate the state plane geodetic grid of the Intergraph CADD base map using a 50 by 50 foot grid cell size. Three time periods were chosen for analysis; 1965, 1985, and fully developed. Zoning classes were chosen to represent the developed land cover within the watershed. A comprehensive zoning scheme was produced by combining the zoning classification used by the various cities.

Figure 4 illustrates land use and urban development evaluated for three time periods: A 2000-foot scale black and white 1965 aerial photograph was used to determine development in 1965. This land-use information was used to calibrate the computer model so that it accurately depicted the basin's response to an actual flood event. The model was calibrated to the September 21, 1964 flood, for which there is stream gage and partial rainfall data. This is the Flood of Record for the basin since 1886. The 1965 land-use map shows the upper basin mostly agricultural or undeveloped; The existing land-use was obtained from a 2000-foot scale black and white December 1985 photograph, and was used to determine existing development for the FEMA Flood Insurance Study Update. The future condition was assumed to be complete development of the comprehensive zoning plan. This condition was used to predict runoff for the fully-developed watershed and to identify potential flooding problem sites.

The fully developed land use classification scheme was compiled from Addison, Dallas, Plano, and Frisco zoning maps, all with different scales and input into the Intergraph CADD system. This data was also translated and incorporated into the raster GIS. The degree of development, as well as composite percent imperviousness and urbanization, were quickly determined for each of the 205 sub-drainage areas for each time period.

Sub-basin delineations were digitized into the Intergraph CADD from 7.5 minute USGS quadrangle maps, Figure 5. The sub-drainage map was translated so that the map could be used to summarize land cover information from the three time periods.

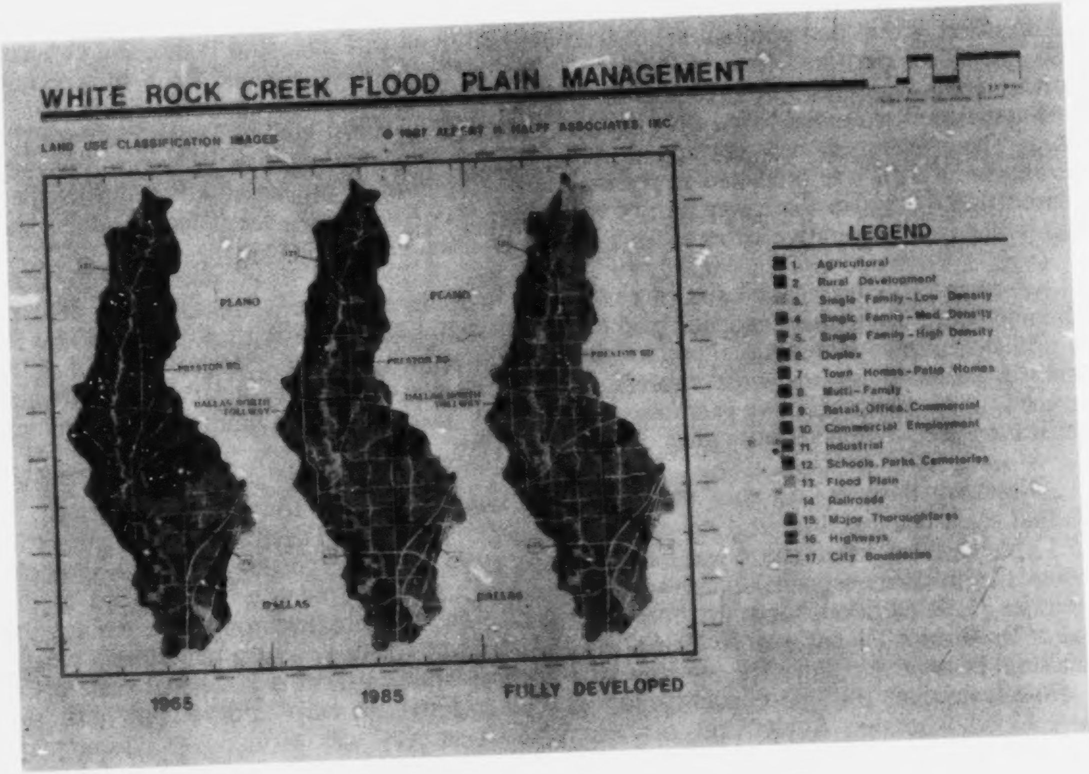

WHITE ROCK CREEK FLOOD PLAIN MANAGEMENT
LAND USE CLASSIFICATION IMAGES
© 1987 ALBERT H. HALFF ASSOCIATES, INC.
PLANO
PRESTON RD.
DALLAS NORTH TOLLWAY
DALLAS
1965
1985
FULLY DEVELOPED
LEGEND
1. Agricultural
2. Rural Development
3. Single Family - Low Density
4. Single Family - Med. Density
5. Single Family - High Density
6. Duplex
7. Town Homes - Patio Homes
8. Multi - Family
9. Retail, Office, Commercial
10. Commercial Employment
11. Industrial
12. Schools, Parks, Cemeteries
13. Flood Plain
14. Railroads
15. Major Thoroughfares
16. Highways
17. City Boundaries

FIGURE 4 - 1965, 1985 AND FULLY DEVELOPED LAND USE FOR THE WHITE ROCK CREEK WATERSHED

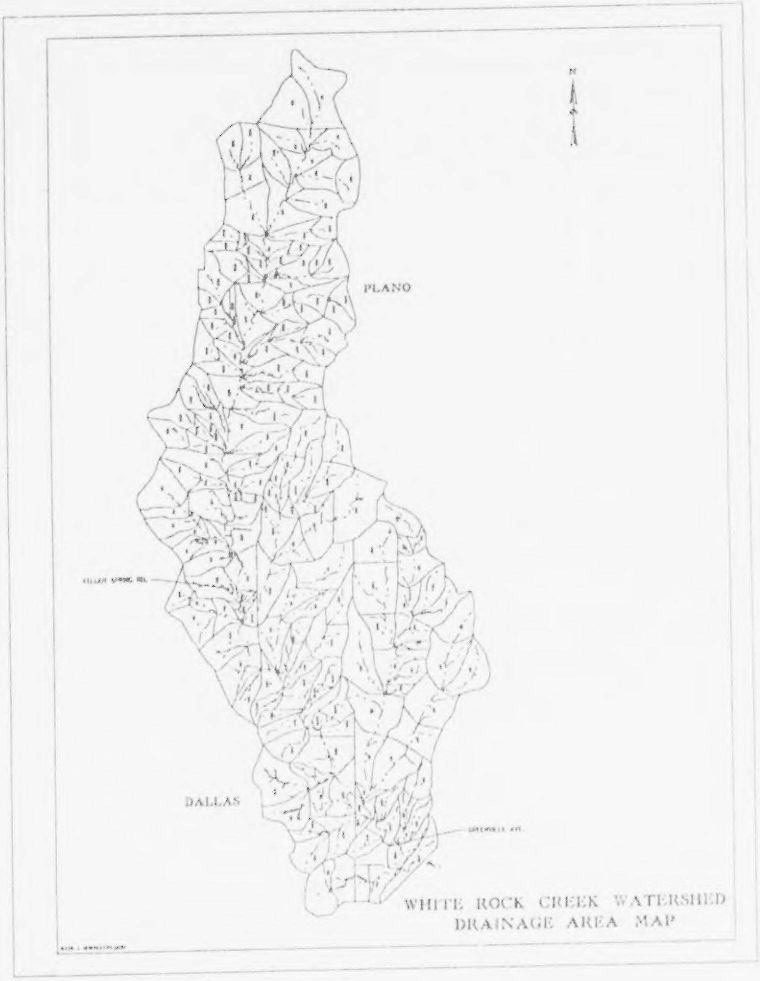


FIGURE 5 - SUB-DRAINAGE AREAS FOR THE WHITE ROCK CREEK WATERSHED.

Two important parameters used to model the urban rainfall/runoff process are percent of urbanization and percent of imperviousness. To determine the percent imperviousness and urbanization that characterizes each zoning class, the impervious area was measured for each of Plano's seventeen zoning categories. Impervious cover was digitized from enlarged aerial photographs (scale 1"=100') for several sample areas in each zoning class.

The sample areas were video-digitized with a Cohu black and white television camera. The individual video frames were processed using a level slice algorithm to delineate gray levels that best represented impervious cover, percent impervious cover measured in the manner compared favorably to the measurements made by hand-digitizing. Therefore, several additional examples were video-digitized to determine a representative percent of imperviousness for fourteen classes used in this study.

A hydrologic analysis was performed at Keller Springs Road and at Tributary 5B30 using data derived from a 1986 Landsat TM satellite image, which was classified and geo-referenced to the GIS for comparison to the December 1985 aerial photographs. Preliminary results show close agreement between the Landsat TM and the 1985 aerial photographs. The analysis also shows an increase in urbanization and a resulting increase in imperviousness for three time periods as a result of development.

Table 3 summarizes the discharges calculated for 1965 existing and future time periods (including Landsat TM results). Based on these results, TM classification yielded results within a few percentage points of the conventional method. We feel classification of TM data, which requires about 1/5 of the manpower of the current digitized method, is a promising way to evaluate land use for urban rainfall/runoff modeling. Incorporating remote sensing, image processing, and GIS allows us to perform comprehensive watershed basin analysis with more accuracy and efficiency than in the past.

TABLE 3 - UPPER WHITE ROCK CREEK WATERSHED LAND USE AND DISCHARGE COMPARISON.

YEAR	% URBANIZATION	% IMPERVIOUSNESS	100 YEAR EVENT MAIN CHANNEL cfs
1965	3	2	28,700
1985 (aerial photos)	31	18	27,900
1985 (Landsat TM)	36	21	28,300
Fully Developed	89	56	30,200
% Increase - Fully Developed vs. Existing	187	211	8.2

Figure 6 illustrates a section of the Intergraph three dimensional data created for the flood-plain management project. Halff Associates has developed software to take cross section profiles from Intergraph three-dimensional CADD files to produce HEC-2 hydraulic models for a watershed. We are enhancing this process and further automating transfer of data between the CADD topographic files, a raster GIS component, and the hydrologic models, NUDALLAS, HEC-2 and the stream sediment transport model HEC-6. The three latter programs have all been developed by the U.S. Army Corps of Engineers.

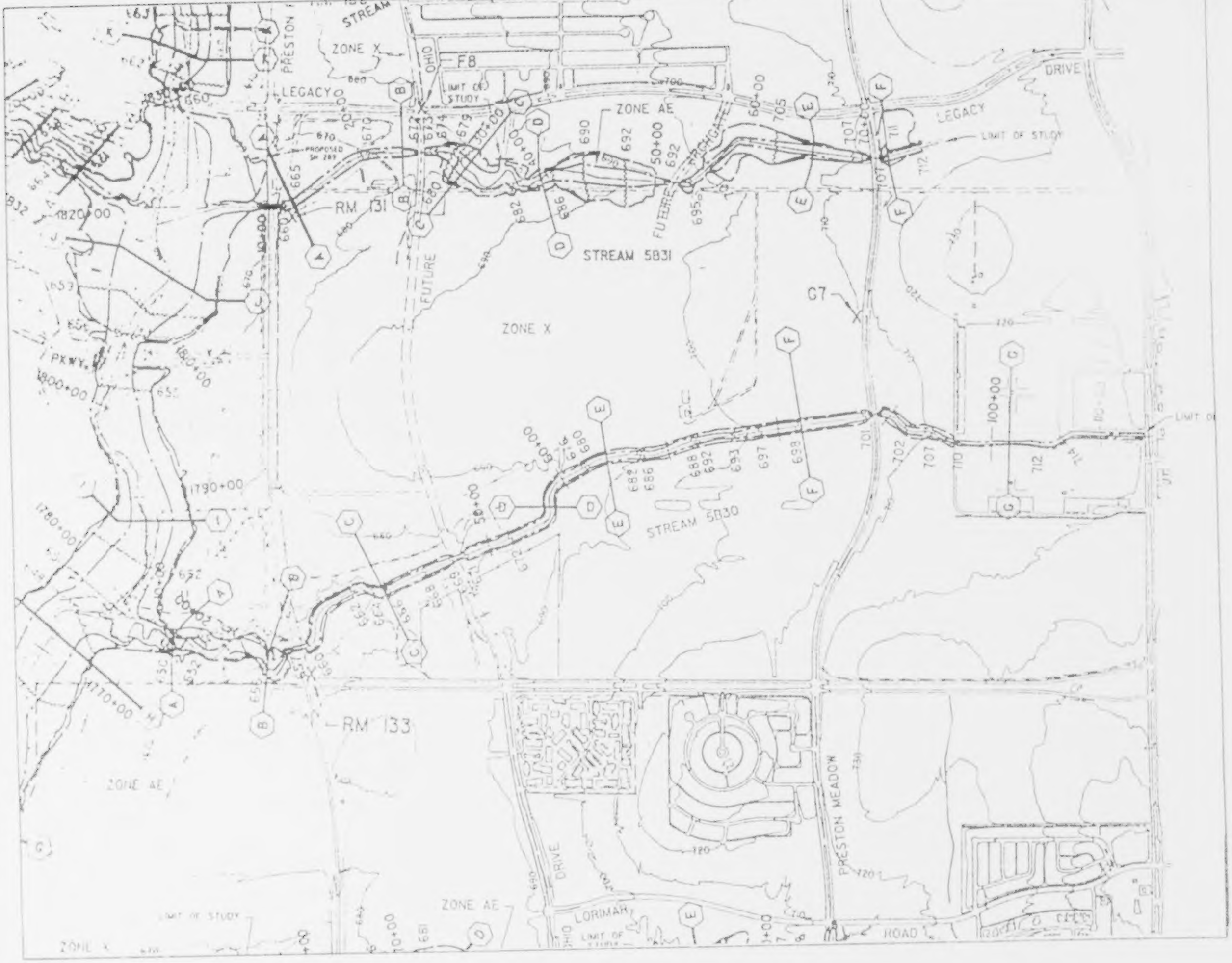

STREAM
ZONE X
PRESTON
OHIO
F8
LEGACY
LIMIT OF STUDY
ZONE AE
DRIVE
LEGACY
LIMIT OF STUDY
PROPOSED SH 289
RM 131
FUTURE
STREAM 5831
G7
ZONE X
PKWY.
STREAM 5830
RM 133
ZONE AE
PRESTON MEADOW
DRIVE
ZONE AE
LORIMAR
ROAD
LIMIT OF STUDY
ZONE X

FIGURE 6 - INTERGRAPH THREE-DIMENSIONAL CONTOUR AND PLANIMETRIC AERIAL PHOTOGRAPHY FOR THE WHITE ROCK CREEK FLOOD PLAIN MANAGEMENT PROJECT.

SUMMARY

The development of land and other resources requires careful consideration of environmental consequences. Natural and man-made features of a site must be studied as interrelated factors, in order to understand the probable effects of any proposed development plan. Remote sensing and computer technology offer exiciting new ways of analyzing the complex relationships between humankind and earth's resources.

Utilizing satellite imagery and other remotely-sensed data, scientists can truly evaluate the large-scale resources and impacts of a given project. Processed images are merged with Intergraph map data, then analyzed with the aid of computer models and Geographic Information Systems.

REFERENCES

ARNOFF, S. and PARLIAMENT, H., 1987, "From Data to Information-Image Processing for Decision Making," Geocarto International Vol.3, pp.25-30.

CERMAK, R.J., FELDMAN A., and WEBB, R.P., 1981, "Hydrologic Land Use Classification Using Landsat," *In Proceedings*: Satellite Hydrology, Fifth Annual William T. Pecora Memorial Symposium, American Water Resources Association, St. Anthony Falls Hydraulic Laboratory, Minneapolis MN., pp.262-269.

CROWDER, B.M., 1987, "Economic costs of reservoir sedimentation: A regional approach to estimating cropland erosion damages," Journal of Soil & Water Conservation, Vol.42, No.3, pp.194-197.

DEUTSCH, M., WIESNET, D.R., and RANGO, A., 1981, Editors, Satellite Hydrology, Fifth Annual William T. Pecora Memorial Symposium, American Water Resources Association, St. Anthony Falls Hydraulic Laboratory, Minneapolis MN.

DRAPER, S.E., and RAO, S.G., 1986, "Runoff Prediction Using Remote Sensing Imagery," Water Resources Bulletin, American Water Resources Association, Vol.22, No.6, pp. 941-949.

GERSMEHL, P.J., 1987, "Use of a Cellular Geographic Information System in Assessing Soil Erosion and Sediment Deposition in Two Medium-Sized Watersheds," *In Proceedings*: URISA-25th Annual Conference, Vol.I, Land Records / Natural Resources pp.140-151.

GILLILAND, M.W. and BAXTER-POTTER, W., 1987, "A Geographic Information System to Predict Non-Point Source Pollution Potential," Water Resources Bulletin, American Water Works Association, Vol.23, No.2, pp.281-291.

GOODENOUGH, D.G. 1988, "Thematic Mapper and SPOT Integration with a Geographic Information System," Photogram. Engineering & Remote Sensing, Vol.54, No.2, pp. 167-176.

JOHANNSEN, C.J. 1983, "Resource information for conservation decisions," Journal of Soil & Water Conservation, November-December, pp.444-445.

LOGAN, T.L. and BRYANT, N.A., 1987, "Spatial Data Software Integration: Merging CAD/CAM/Mapping with GIS and Image Processing," Photogram. Engineering & Remote Sensing, Vol.53, No.10, pp.1391-1395.

MAFFINI, G., 1987, "Raster Versus Vector Data Encoding and Handling: A Commentary," Photogram. Engineering & Remote Sensing, Vol.53, No.10, pp.1397-1398.

OSLIN, A.J., 1987, "Geographic information system implementation and multi-temporal image processing as a method for modeling and detecting change in a diverse forested region of Texas," Dissertation. May, 1987. University of Texas at Dallas. Richardson, Texas.

RAHM, P.H., 1981, "Remote Sensing of Bank Erosion Along the Missouri River, South Dakota," *In Proceedings*: Satellite Hydrology, Fifth Annual William T. Pecora Memorial Symposium, American Water Resources Association, St. Anthony Falls Hydraulic Laboratory, Minneapolis MN., pp.697-700.

RANGO, A., 1985, "Assessment of Remote Sensing Input to Hydrologic Models," Water Resources Bulletin, American Water Resources Association, Vol.21, No.3, pp.423-432

ROBINSON, V.B. and FRANK, A.U., 1987, "Expert Systems for Geographic Information Systems," Photogram. Engineering & Remote Sensing, Vol.50, No.10, pp.1435-1441.

TALBOT, S., 1986, "The Use of Mapping Information Management Systems in the City of New York," *In Proceedings*: ACSM-ASPRS Annual Convention March 1986, Washington D.C., Vol.3-GIS, pp.12-20.

TOMASELLI, L.K. and GILHOUSEN, M., 1987, "Digitized Regional Land Use Inventory for the Twin Cities Metropolitan Area," *In proceedings*: URISA 25th Annual Conference, August 1987, Fort Lauderdale, Fl. Vol.4, pp.73-82.

MITAS: A NEW SYSTEM FOR INTERACTIVE MULTISPECTRAL SCENE ANALYSIS

R. Karalus

U.S. Army Engineer Topographic Laboratories

and

C. Sheffield

and

M. Place

Earch Satellite Corporation

and

A. Downs

PAR Technology

ABSTRACT

Resource management and terrain analysis in the Corps of Engineers increasingly call for multispectral and multi-source data. The MITA System (Multispectral Interactive Terrain Analysis System) now under development for the COE Engineer Topographic Laboratories, Fort Belvoir, embodies a suite of capabilities designed for both practical application and R&D use. This paper describes the MITAS general design and particular modeling capabilities, with these emphases:

(1) Processing of multispectral and hyperspectral image data.

(2) Data registration, geometric correction, and radiometric correction.

(3) Automated approaches to scene classification and information extraction, employing multispectral and multi-source data.

(4) Sophisticated atmospheric modeling applied to change detection for multispectral techniques and terrain feature extraction.

(5) Source data combination for image enhancement.

(6) Provision for inclusion of rule based and expert system algorithms.

(7) Interactive, menu-driven structure permitting both softcopy and hardcopy products.

(8) Complete session histories for every system run.

The MITA System is designed for use by application specialists with minimal computer experience, while permitting the experienced user to dispense with system prompts and unneeded system feedback.

CAPABILITIES AND LIMITATIONS OF CD-ROM OPTICAL DIGITAL DISKS FOR STORING REMOTE SENSING DATA; TRENDS IN REMOTE SENSING AND GIS'S

Daniel J. Costanzo

U.S. Army Engineer Topographic Laboratories
Topographic Developments Laboratory
Mapping Developments Division
Data Base Development Branch, Ft. Belvoir, VA

ABSTRACT

The Compact Disk - Read Only Memory (CD-ROM) is a new technology offering a unique and unusual medium for storing remote sensing data on optical digital disks. A single 4.72 inch diameter CD-ROM disk can hold 550 Megabytes of digitized remote sensing imagery, and other data. Interfacing to a microcomputer, provides low-cost, and rugged means of accessing large data bases in field or office environments for water resource management.

Commercial CD-ROM based systems are being produced by several vendors. Several civilian and military remote sensing and mapping organizations are also currently considering using CD-ROM. Unfortunately, little concrete information is readily available on adapting this technology to remote sensing applications in water resource management. This paper will address these capabilities and limitations peculiar to storing remote sensing data on CD-ROM optical disks, through examples using remote sensing products utilized in water resource management. Emphasis will be placed on needs of small, low-cost, decentralized systems and GIS's.

The paper will cover the following areas of CD-ROM technology relevant to remote sensing data storage: data preparation, storage techniques and capacities, bit error rates, data compression, software indexing, and media longevity. It will also touch upon issues of: access and processing time, data transmission, system design, cost-benefit analysis, data security, and legal aspects of CD-ROM. The paper will then discuss future directions for CD technology of interest to the USACE remote sensing community. Finally, it will describe remote sensing storage investigations into CD-ROM being performed at the U.S. Army Engineer Topographic Laboratories.

DESIGN ISSUES: INTEGRATING IMAGERY AND OTHER GEOGRAPHIC DATA SOURCES WITHIN GRASS

Michael Shapiro

and

William Goran

and

Robert Lozar

U.S. Army Construction Engineering Research Lab
Champaign, IL

ABSTRACT

Researchers in the Environmental Division of the U.S. Army Construction Engineering Research Laboratory have developed an integrated geographic information and image processing system called GRASS - Geographic Resources Analysis Support System. GRASS was developed for environmental planners and resource managers on military installations, but it is now also being used by a number of federal agencies, universities, and other organizations.

Integrating GIS and image processing functions presents several advantages to users. GIS layers consist of interpreted data layers (e.g. soils, land use and administrative boundary maps), while remotely sensed imagery consists of raw, uninterpreted data. Integrating imagery with GIS data allows users to monitor changing land conditions, update and modify pre-interpreted data layers, and generate new interpretations. Also, imagery can provide a useful visual reference and ground truth for other interpreted data sets. Further, many of the image processing functions, such as georeferencing and neighborhood analysis, are useful with other data layers, and many GIS functions, such as masking, feature isolation, and map algebra, are useful with imagery data. Combining these functions

in a single system avoids duplication and saves users the time and trouble of moving files from one system to another.

While the advantages of integrating GIS image processing functions are clear, there are many differences between imagery and other GIS data files. First, imagery files tend to be much larger than other GIS data layers. This size difference often causes variations in system design (and hardware) - with GIS systems usually reading data from hard disk, and image processing systems reading directly from 1/2" tape drives. Second, imagery band files are uniquely associated to represent images, and some specialized format is needed to accommodate this association. Third, imagery files are not referenced to a cartographic base, thus a georeferencing process is required before these files can be integrated with other GIS data files. However, the georeferencing process involves resampling and therefore alters the original data - so results of analysis functions may vary somewhat depending on whether or not images have been georeferenced.

This paper discusses how these and other design issues are handled within GRASS, and how GRASS interacts with other image processing and GIS systems.

REMOTE SENSING AND COMPUTER MAPPING ACTIVITIES OF THE TEXAS NATURAL RESOURCES INFORMATION SYSTEM

Charles Palmer

Texas Natural Resources Information System
P.O. Box 13231 Capitol Station
Austin, TX

ABSTRACT

From the early 1970s, with the testing of NASA's "Detection and Mapping (DAM) Package," through a multi-year technology transfer grant funded by NASA in the late 1970s and early 1980s, the Texas Natural Resources Information System (TNRIS) has worked toward making remote sensing technology an operational tool for State natural resource managers. By providing technical assistance through joint projects, TNRIS has assisted several State agencies develop expertise in the use of remotely sensed data. More recently the emphasis has shifted to include computer mapping and geographic information systems for analysis and display of the data. While pursuing remote sensing and GIS projects, TNRIS continues its function as distributor of natural resource data for Texas.

APPLICATIONS OF LANDSAT TM FOR THE DEVELOPMENT OF THE COOPER LAKE MASTER PLAN

Tamie R. Morgan

U.S. Army Corps of Engineers
Fort Worth, TX

ABSTRACT

Landsat TM imagery was used to produce a vegetative cover map as part of the documentation of the Cooper Lake Master Plan. Selected pool elevations and project boundaries were digitized and matrixed into the vegetative cover data base using the ERDAS (Earth Resources Data Analysis System) GIS capabilities. Quantitative analysis was performed to determine the impact of the reservoir on the vegetative cover. Once established, this data base made it possible to produce a variety of related maps and plans including: Wildlife Management Plan, Selected Pool Elevations Map, Water Use Plan, Land Use Allocation Plan, and Vegetative Cover Map. Color prints for the document were created using a three color separation negative of hard copy prints from a Tektronix 4695 printer.

THE CORPS DEVELOPMENT OF A HELICOPTER LIDAR BATHYMETER SYSTEM

W. Jeff Lillycrop
and
Joan Pope

Engineering Development Division
Coastal Engineering Research Center
U.S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180-0631

ABSTRACT

The U.S. Army Corps of Engineers conducts an extensive annual surveying program in support of its Federal water resource projects. The program includes both regional and site-specific missions covering a broad range of project types including navigation and erosion control. The most resource demanding survey requirement is the need for quick, accurate, controlled-grid bathymetric surveys. Present hydrographic surveying methods utilize fathometers which are slow and produce surveys dependent upon water surface elevation. This paper discusses a new direction in bathymetric surveying and the Corps' involvement in the conceptual design and planned construction of a Helicopter Lidar Bathymeter System (HLBS). The HLBS will be unique in several aspects compared to the few existing fixed-wing lidar bathymeter systems. The main differences include the use of a helicopter to allow for controlled profiling as well as scanning data acquisition and data collection independent of water surface elevation. This paper presents the status of the Corps of Engineers' activities in designing and acquiring a Helicopter Lidar Bathymeter System.

THE CORPS DEVELOPMENT OF A HELICOPTER LIDAR BATHYMETER SYSTEM

W. Jeff Lillycrop
and
Joan Pope

Engineering Development Division
Coastal Engineering Research Center
U.S. Army Engineer Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180-0631

The U.S. Army Corps of Engineers (USACE) conducts an extensive annual hydrographic surveying program in support of the planning, design, construction, and maintenance of Federal water resource projects. The USACE surveying program includes both large-scale regional and site-specific missions, bathymetric and topographic localities, and a broad range of project types including flood control, navigation, and erosion control. The most resource demanding survey requirement is the need for quick, accurate, controlled dense bathymetric surveys of riverine, coastal, harbor, lake, and channel areas.

Present USACE hydrographic surveying procedure utilizes acoustical depth sounders (i.e. fathometers) and/or lead-lines to directly sound the bottom. Both procedures are dependent upon access to the water surface and datum control on a fluctuating surface. Horizontal position control is usually based on measuring the distance of offset from a known ground control station via a tagline or multi-range (i.e. microwave or VHF) or range-azimuth positioning system. Horizontal control for regional area coverage surveys is usually through a multi-range positioning system. USACE has tested other surveying techniques, several of which are being used on a limited scale. However, each alternative system has been found to have unacceptable accuracy, efficiency, or cost limitations over standard procedures which restricts general application. Several problems which plague the USACE's hydrographic surveying program could be alleviated through the development of a Helicopter Lidar Bathymeter System (HLBS). Such a system would be independent of the water surface, readily transportable between projects, and faster than present procedures. An HLBS would support the USACE's surveying program by providing a potentially more economical alternative for certain projects in clearer waterways.

Measurement of water depth with a laser was first proposed in the mid-1960's and was field-demonstrated in 1968. In the mid-1970's the National Aeronautics and Space Administration (NASA) sponsored the design and development of the Airborne Oceanographic Lidar (AOL) system. AOL has been used to measure nearshore bathymetry and topography in several demonstration tests sponsored by the National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency (EPA), the U.S. Navy, and the USACE. In the late 1970's, the Naval Ocean Research and Development Activity (NORDA) initiated development of the Hydrographic Airborne Laser Sounder (HALS). Operational testing of the HALS has recently concluded. The Australian and Canadian Governments have sponsored development of Lidar bathymetry systems, the LADS and the LARSEN, respectively. All four systems are designed for use in a fixed-wing aircraft and intended for broad base regional hydrographic mapping.

The USACE is currently involved in a joint project with the Canadian Government for design, construction, and field verification of a Lidar topographic and bathymetric surveying system. The lead Corps Of Engineer agency for this activity is the Coastal Engineering Research Center at the Waterways Experiment Station. The system is being designed for use out of a standard-sized commercial helicopter (i.e. Bell 205 or equivalent in size, power, and load capacity) at operational altitudes ranging from 100 to 200 meters. The design of the HLBS will be optimized for greatest accuracy in water depths of less than 15 meters with total system elevation accuracies including hardware, software, and positioning objectives equal to fathometer standards. Helicopter positioning will utilize several systems such as microwave, Global Positioning System (GPS), inertial, and range-azimuth.

The project has been divided into two phases. Phase I, which should require about 6 months to complete, includes development of the performance specifications for all system components, expected operational restrictions, and anticipated system performance standards. Phase II will include the detailed system design and construction, and field testing the HLBS, requiring about 18 months to complete.

Phase II will culminate with several production level field demonstrations where typical Corps project survey sites will be surveyed with the HLBS and compared with conventual surveys of the same location. These field tests have three major purposes. The first is to field verify that the HLBS is operational as specified. The second is to determine the efficiency of system operation under a range of field conditions. The third is to demonstrate the operational HLBS to Corps users.

System components include a Nd:YAG laser transmitter capable of emitting two simultaneous optical pulses (an infrared wavelength to accurately locate the water surface and a green wavelength capable of penetrating the water column and accurately detecting the bottom); a data acquisition system to acquire and store all sensed data such as time, range, and position; a guidance system to provide the pilot with realtime navigation guidance in order that a pre-established survey grid can be followed; an aircraft attitude recorder for use in correcting all altitude data for the effects of aircraft pitch, roll, and yaw; a positioning system such as multi-range, inertial, Global Positioning System (GPS), range-azimuth, or a combination of systems; a system status panel so the operator can monitor system parameters and confirm that valid data are being collected. To support the HLBS a ground-based system which post-processes the data collected into planimetric drawings, topographic sheets, beach profiles, or channel sections will be an integral part of this project.

Specific system features include accuracy standards comparable to current fathometer surveys with no loss of accuracy. The system will be capable of collecting both topographic and bathymetric data without requiring system modifications during flight. This is critical when performing beach profile surveys. The helicopter will be able to fly across the beach face and offshore while continuously collecting data. Elevations computed will be independent of water surface elevations. This will remove problems associated with tide and long period wave induced elevation changes in the coastal zone. The system will be capable of operating in a scanning or profiling mode. The scanning mode will allow for faster coverage of large areas while the profiling mode will allow for dense coverage of specific areas.

All airborne components will be modular for easy shipment, installation, removal, and operation out of the helicopter. A dedicated helicopter is not required for this system, instead the system is being designed for installation out of a chartered aircraft. This allows greater flexibility in use and a more cost-effective system.

Along with the system hardware, software is also being developed for reduction, analysis, and presentation of collected data. From initial data collection through plotting planimetric sheets and calculating dredging volumes or beach cross sectional areas, the system will be highly automated.

The HLBS will have operational limitations where it can most effectively and economically be used. Along much of the northern and southern coastal areas of the United States and the intercoastal waterways, the system will be ideal. However, water clarity is a primary factor in accurate data collection. In rivers, the middle latitudes, and some inlets where turbid waters are frequently present, the system will not be effective.

The presently programmed schedule for the project allows for initiation of Phase I in early 1988 with Phase II beginning near the end of the summer.

This study is being conducted under the project, "Helicopter Lidar Bathymeter Development Program" of the United States Army Corps of Engineers by the Coastal Engineering Research Center, Waterways Experiment Station. The Office, Chief of Engineers, is acknowledged for authorizing publication of this paper.

APPENDIX A

LIST OF ATTENDEES

David Aimsbury
NASA,Johnson Space Flight Center
Houston, TX 77058

Adolph Anderson
U.S. Amry Engr. Waterways
Experiment Station
WES Bldg. 1000
Halls Ferry Road
P.O. Box 60
Vicksburg, MS 39180-0060

Pat Ashburn
USDA/FAS
Parklawn BLdg.
5600 Fishers Lane
Rockville, MD 20857

Larry Banks
U.S. Army Engr. Div., Southwestern
1114 Commerce Street
Dallas, TX 75242-0216

Manuel Barnes
U.S. Army Engr. Dist., Little Rock
P.O. Box 867
Little Rock, AR 72203-0867

Clay R. Bassham
Texas A&M University
Pelican Islands
Galveston, TX 77550

Marcy Berbrack
P.O. Box 13231
Austin, TX 78767

Pete Biggan
5203 Villa Del Mar
Arlington, TX 76012

Steve Bong
U.S. Army Corp Engr.
Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180-0060

Bill Boyd
9175 Gilford Road
Columbia, MD 21046

Andrew Bruzewicz
U.S. Army Engr. Dist., Rock Island
Clock Tower Building
P.O. Box 2004
Rock Island, IL 61204-2004

Curtis J. Carley
U.S. Army Engr. Dist., Albuquerque
P.O. Box 1580
517 Gold Avenue, S.W.
Albuquerque, NM 87103-1580

Gary Case
Lockheed Corp.
1911 Jefferson Davis Highway
Arlington, VA 22205

Richard Clark
ASI
Lakewood, CO 80215

William V. Clement
U.S. Army Engr. Dist., Portland
P.O. Box 2946
Portland, OR 97208-2946

Steve Colwell
Trimble Navigation
Conroe, TX 77301

Michael Corkran
U.S. Army Engr. Dist., Tulsa
P.O. Box 61
Tulsa, OK 74121-0061

Daniel J. Costanzo
U.S. Army Corps of Engineers
Humphreys Engineers Center
Telegraph & Leaf Roads (Bldg. 2592)
Fort Belvoir, VA 22060-5580

Dan Cotter
U.S. Army Corps of Engineers;
Headquarters
20 Mass. Ave., NW
Washington, DC 20314-1000

Robert Cunningham
U.S. Army Engr. Dist., New Orleans
P.O. Box 60267
New Orleans, LA 70160-0267

Dennis Darling
4210 Oaksprings Ct.
Arlington, TX 76016

Richard B. Davis
R.B. Davis Co.
711 H St.
Crescent City, CA 95531

Lewis Decell
U.S. Army Engr. Waterways
Experiment Station
WES Bldg. 1000
Halls Ferry Road
P.O. Box 60
Vicksburg, MS 39180-0060

Jim Deigan
Earthsat
7222 47th Street
Chevy Chase, MD 20815

Patricia A. Denning
Fort Belvoir, VA 22060

Morris Deutsch
Satellite Hydrology, Inc.
103 Beulah RD. NE
Vienna, VA 22180

Alex Dolgos
U.S. Army Engr. Dist., Baltimore
P.O. Box 1715
Baltimore, MD 21203-1715

James Ebert
Ebert & Associates
3100 9th St., NW
Albuquerque, NM 87107

Henry A. Edwardo
U.S. Army Engr. Dist., Pittsburgh
Planning Division, Room 1907
1000 Liberty Avenue
Pittsburgh, PA 15222-4186

Jean Epperson
Texana Heritage Services
Deer Park, Tx 77536

James Farely
Arkansas Archeological Survey
Fayetteville, AR 72701

Mike Fedosh
U.S. Army Engr. Dist., New York
26 Federal Plaza
New York, NY 10278-0090

Arlen Feldman
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616-4687

Dick Fleischman
U.S. Army Engr. Dist., Rock Island
Clock Tower Building
P.O. Box 2004
Rock Island, IL 61204-2004

Lars M. Forsman
U.S. Army Corps Engr.
Regulatory Functions Branch
211 Main Street
San Francisco, CA 94105-1905

Roy Fort
Del Norte Tech
Hoston, TX 77052

William W. Fowler
U.S. Army Engr. Dist., Alaska
P.O. Box 898
Anchorage, AK 99506-0898

Nate Fuller
Ohio Geological Survey
Lake Erie Section
P.O. Box 650
Sandusky, OH 44870

William Fullen
Texas Heritage Services
Deer Park, TX 77536

Alan Galdis
U.S. Army Corps of Engr. Dist. Mobile
P.O. Box 2288
Mobile, Al 36628-0001

Stanley Gardner
U.S. Geological Service
National Mapping Division
Building 3101
NSTL, MS 39529

Richard Garintz
Fort Belvoir, VA 22060

Dick Garrity
U.S. Army Corps of Engineers
Topographic Labs
Building 2592, ETL-LU
Ft. Belvoir, VA 22060-5546

Clyde P. Gates
U.S. Army Engr. Dist., Little Rock
P.O. Box 867
Little Rock, AR 72203-0867

Roger Gauthier
U.S. Army Engr. Dist. Detroit
ATTN: NCEED-L
P.O. Box 1027
Detroit, MI 48231-1027

Linda Glenboski
U.S. Army Engr. Dist., New Orleans
P.O. Box 60267
New Orleans, LA 70160-0267

Vicki Goodnight
U.S. Army Engr. Div., Southwestern
1114 Commerce Street
Dallas, TX 75242-0216

Bob Harbaugh
U.S. Army Engr. Dist., Galveston
P.O. Box 1229
Galveston, TX 77553-1229

Roger Harris
Fort Belvoir, VA 22060

John W. Hart
U.S. Army Engr. Dist., Ft. Worth
P.O. Box 17300
Fort Worth, TX 76102-0300

Marty Hathorn
5512 Durham
Fort Worth, TX 76114

Joanne Haus
ASI
Lakewood, CO 80215

William R. Hazard
4603 Edgemont Drive
Austin, TX 78731

Jeff Heath
U.S. Army Engr. Dist., Chicago
219 S. Dearborn St.
Chicago, IL 60604-[illegible]

Alastair Helme
Wild Heerbrugg Instruments, Inc.
465 Smith St.
Farmingdale, LI, NY 11735

James J. Hester
U.S. Army Engr. Dist., Vicksburg
P.O. Box 631
Vicksburg, MS 39180-0060

Robert K. Holz
Department of Geography
University of Texas
200 West 21st St.
Austin, TX 78712

Joseph S. Hughes
U.S. Army Engr. Dist., Kansas City
700 FOB
601 East 12th Street
Kansas City, MO 64106

Dennis Johnson
Ft. Bragg, NC 28307

William C. Jones
U.S. Army Engr. Dist., Omaha
215 North 17th Street
Omaha, NE 68102-4978

Richard D. Jongs
U.S. Army Engr. Dist., Galveston
P.O. Box 1229
Attn: CESWG-CO-RC
Galveston, TX 77553-1229

Aaron Katz
U.S. Army Engr. Dist., Galveston
P.O. Box 1229
Galveston, TX 77553-1229

Dan B. Keir
U.S. Army Engr. Dist., Wilmington
308 Water Street
(Federal Building)
Wilmington, NC 28402-1980

Carroll Kelinhans
U.S. Army Engr. Dist., New Orleans
P.O. Box 60267
New Orleans, LA 70160-0267

Robert Kessell
Fort Belvoir, VA 22060

Joe King
EOSAT, Inc
4300 Forebes Boulevard
Lamham, MD 20706

Willliam L. Klesch
U.S. Army Corps of Engineers
Pulaski Bldg.-CECW-P
20 Mass Ave., NW
Washington, DC 20314-1000

Chester Kos
U.S. Army Const. Engineering
Research Laboratory
P.O. Box 4005
Champaign, IL 61820-1305

Gary Kratochvil
Astronaut Office
Johnson Space Center
Hoston, TX 77058

Rose Kress
U.S. Army Engr. Waterways
Experiment Station
P.O. Box 631
Vicksburg, MS 39180-0631

Peter La Flamme
U.S. Army Engr. Div., Southwestern
1114 Commerce Street
Attn: SWDO-IMP
Dallas, TX 75242-0216

Nancy La Potin
U.S. Army Cold Region Research
and Engineering Laboratory
72 Lyme Road
Hanover, NH 03755-1290

Col. Alan Laubscher
U.S. Army Corps of Engineers
Leaf and Telegraph
Cude Building
ATTN: CEETL-TC-S
Fort Belvoir, VA 22060-5546

David Langlois
U.S. Army Cold Region Research
and Engineering Laboratory
72 Lyme Road
Hanover, NH 03755-1290

Karen Lee
P.O. Box 1017
Detroit, MI 48232

Scott Leibowitz
Louisiana State University
Highland Rd.
Baton Rouge, LA 70803

Joddi Leipner
NASA Ames Research
Moffett Field, CA 94035

David Lichy
U.S. Army Corps of Engineers
Water Resources Support Center
Casey Building
Ft. Belvoir, VA 22060-5586

Steve Lieber
Wild Heerbrugg Instruments, Inc.
465 Smith St.
Farmingdale, LI, NY 11735

Jeff Lillycrop
Coastal Engineering Research Center
P.O. Box 631
Vicksburg, MS 38180-0631

Bryan Logan
Photo Science, Inc
7840 Airpack Rd.
Gaithersburg, MD 20879

Robert Lozar
U.S. Army Const. Engineering
Research Laboratory
P.O. Box 4005
Champaign, IL 61820-1305

Craig G. Lufkin
DBA Systems, Inc.
11781 Lee Jackson Hwy.
Fairfax, VA 22033

Ross Lunetta
U.S. Army Engr. Dist., Detroit
P.O. Box 1027
Detroit, MI 48231 1027

Jack Mackey
SPOT Image Corp.
1897 Preston White Drive
Reston, VA 22091-4326

Paul Mann
U.S. Army Engr., Dist., Albuquerque
P.O. Box 1580
Albuquerque, NM 87103-1580

Paul Mason
U.S. Army Engr. Dist., Wilmington
308 Water Street
(Federal Building)
Wilmington, NC 28402-1890

Kerry Mc Alister
Mc Alister Aerial Surveys
2203 Taylor-Simonetti
Austin, TX 78728

Richard C. Mc Ardle
Department of Agriculture
14th St. & Independence Ave.,NW
Washington, D.C. 20250

Boyd K. Mc Clellan
U.S. Army Engr. Dist., Louisville
Attn: ORLED-S
P.O. Box 59
Louisville, KY 40201-0059

Harlan L. Mc Kim
U.S. Army Cold Regions Research
and Engineering Laboratory
72 Lyme Road
Hanover, NH 03755

Eugene Meier
Las Vegas, NV 89101

Rae Melloh
USACE, Cold Regions Research & Engr
Labs
72 Lyme Rd.
Hanover, NH 03755-1290

Elemore Meredith
SPOT Image Corp.
1897 Preston White Drive
Reston, VA 22091-4326

Carolyn J. Merry
U.S. Army Cold Regions Research
and Engineering Laboratory
72 Lyme Road
Hanover, NH 03755-1290

Gary Metz
USGS
Building 3101
NSTL, MS 39529

Bruce H. Moore
U.S. Army Engr. Dist., St. Louis
210 Tucker Blvd. North
St. Louis, MO 63101-1986

Adriene D. Morgan
U.S. Army Engr. Dist., Mobile
P.O. Box 2288
Mobile, Al 36628-0001

Tamie Morgan
P.O. Box 17300
Fort Worth, TX 76102

Tim Mullen
EARDAS
430 10th St.-Suite N206
Atlanta, GA 30318

Philip W. Mulvey
U.S. Army Engr. Dist., Los Angeles
300 North Los Angeles Street
P.O. Box 2711
Los Angeles, CA 90053-2325

Bruce Needham
National Oceanic and Atmospheric Administration
1825 Connecticut Ave.
Suite 500
Washington, DC 20235

John Nichols
U.S. Army Corps of Engineers
Water Resources Support Center
Casey Building
Ft. Belvoir, VA 22060-5586

Kevin W. O'Cullion
E. Coyote Enterprises
P.O. Box 1119
Mineral Wells, TX 76067

Calvin O'Neil
35A Oakhill Lane
Carriere, MS 39426

Gene O'Neil
U.S. Army Engr. Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180-0631

Phil Orlowski
U.S. Army Engr. Dist., Portland
P.O. Box 2946
Portland, OR 97208-2946

Aubie Oslin
A. H. Halff, Associates
Dallas, TX 75221

Barry W. Padgett
U.S. Army Engr. Dist., Mobile
P.O. Box 2288
Mobile, AL 26628-0001

Walter Pankow
U.S. Army Engr. Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180-0631

Joe Paxton
P.O. Box 17300
Fort Worth, TX 76102

Lloyd Penland
40 Technology Park
Norcross, GA 30092

Dan Pette
19 Brair Hollow
Houston, TX 77027

Mike Pucherelli
Bureau of Reclamation
1961 Stout St.
Denver, CO 80202

Bruce Rado
ERDAS Inc.
430 Tenth Street, N.W.-Suite N206
Atlanta, GA 30318

Linda Rao
University of Texas
200 West 21st St.
Austin, TX 78712

Mike Rasher
Soil Conservation Service
P.O. Box 222
Vienna, GA 31092

Stuart Roberts
Texas General Land Office
Austin, TX 78767

Rita Robison
Civil Engineering Magazine
345 East 47th Street
New York, NY 10021

Bob Rolfe
Precision Photo Laboratories
5758 North Webster
Dayton, OH 45414

Dave Ross
217 Cox Road
Conroe, TX 77850

Barry G. Rought
U.S. Army Corps of Engineers
521 Birch
Richardson, TX 75081

Gerard Sala
Sabine River Authority
Orange, TX 77630

Chial Sarnark
Photo Science, Inc.
7840 Airpark Rd.
Gaithersburg, MD 20879

Herbert Schmidt
U.S. Army Engr. Dist., Galveston
P.O. Box 1229
Galveston, Tx 77553-1229

Frank R. Schuter

Judy Scott
U.S. Army Engr. Dist., Ft. Worth
819 Taylor St.
Ft. Worth, TX 76102-0300

Darlene Seyler
U.S. Army Corps of Engineers
Topographic Labs
Building 2592, ETL-LU
Ft. Belvoir, VA 22060-5546

Michael Shapiro
U.S. Army Const. Engineering
Research Laboratory
P.O. Box 4005
Champaign, IL 61820-1305

Denise Shaw
North Texas State University
Denton, TX 76203

Dean Shea
U.S. Army Engr. Dist., Tulsa
224 South Boulder
P.O. Box 61
Tulsa, OK 74121-0061

Gary Shelton
Ames Research Center
Moffett Field, CA 94035

Lee Sikes
Soil Conservation Service
Federal Courts, 501 W, 10th St.
Ft. Worth, TX 76102

Bob Sinclair
Illinois State Water Survey
102 N Neil St.
Champaign, IL 61820

R. D. Smith
U.S. Army Engr. Dist., Galveston
P.O. Box 1229
Attn: CESWG-CO-RC
Galveston, TX 7755

Bob Sneed
U.S. Army Engr. Dist., Nashville
P.O. Box 1070
Nashville, TN 37202-1070

Cecil W. Soileau
U.S. Army Engr. Dist., New Orleans
P.O. Box 60267
New Orleans, LA 70160-0267

Nestur S. Sotelo

Bobby Spiers
Department of Agriculture
14th St & Independence Ave, SW
Washington, D.C. 20250

Don Stauble
U.S. Army Engr. Waterways
Experiment Station
P.O. Box 631
Vicksburg, MS 39180-0631

Allan Steinle
U.S. Army Engr. Dist., Omaha
215 North 17th Street
Omaha, NE 68102-4978

Ronald H. Stoffer, Jr.
110 Whiting
Galveston, TX 77550

Jack Stoll
U.S. Army Corps of Engineers
Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180-0631

Jeffery Tracey
INTERA Technologies
2500,101 6th Ave.,SW
Calgary, Alberta
T2P 3P4 CANADA

Bob Wademan
Sierra/Misco, Inc.
San Jose, CA

Roger Ward
283rd Eng Det.
Fort Bragg, NC 28307

Michael Waring
U.S. Army Engr. Dist., Vicksburg
U.S. Post Office & Courthouse
P.O. Box 60
Vicksburg, MS 39180-0060

Wayne Weaver
U.S. Army Engr. Dist., Ft. Worth
P.O. Box 17300
Fort Worth, TX 76102-0300

Rolf Westgard
3M Company
St. Paul, MN 55101

Katrina Whitehead
U.S. Geological Service
National Mapping Division
Building 3101
NSTL, MS 39529

David A. Whiteman
Moniteq LTD.
630 Rivermede Road
Concord, Ontario
L3K 2H7 Canada

R. Wilkenson
U.S. Army Engr. Dist., Ft. Worth
P.O. Box 17300
Fort Worth, TX 76102-0300

Barry Willey
U.S. Army Engr. Dist., Galveston
P.O. Box 1229
Galveston, TX 77553-1229

Donna Williams
U.S. Army Engr. Dist., Detroit
P.O. Box 1027
Detroit, MI 48231-1027

Paul Wilson
U.S. Army Engr. Dist., Galveston
P.O. Box 1229
Galveston, TX 77553-1229

L. Dosey Worthy
LSU
Highland Rd.
Baton Rouge, LA 70803

Commercial Exhibitors

E. Coyote Enterprises, Inc.
Trimble Navigation
Route 4, Building 228
P.O. Box 1119
Mineral Wells, TX 76067

Del Norte Tech
Houston, Texas 77052

Earth Satellite Corporation
7222 47th Street
Chevy Chase, MD 20815

EPSAT, Inc.
4300 Forbes Boulevard
Lanham, MD 20706

ERDAS, Inc.
430 10th Street, NW, Suite N206
Atlanta, GA 30318

Intera Technologies
2500 101 6th Avenue, SW
Calgary, Alberta
T2P 3P4 CANADA

MASSCOMP
One Technology Way
Westford, MA 01886

Photo Science, Inc
7840 Airpark Road
Gaithersburg, MD 20879

Precision Photo Labs, Inc
5758 Webster Street
Dayton, OH 45414-0595

Sierra Misco, Inc.
San Jose, CA

SPOT Image Corp
1897 Preston White Drive
Reston, VA 22091-4326

Terra Mar Resource Information
Services, Inc.
1937 Landings Drive
Mountain View, CA 94043

Trimble Navigation
Conroe, Texas

Wild Heerbrugg Systems
Suite 207
373 Inverness Dr.
Englewood, CO 80